DEFENSE SYSTEMS MANAGEMENT

REVIEW

DEPARTMENT OF DEFENSE · SYSTEMS MANAGEMENT COLLEGE ·

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VOL I, NO 4.

AUTUMN 1977

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The Defense Systems Management Review is published quarterly by the Defense Systems Management College, Fort Belvoir, VA 22060. Publication of the Review was approved by OASD(PA) May 18, 1976.

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DEFENSE SYSTEMS MANAGEMENT REVIEW

PURPOSE

The purpose of the Defense Systems Management Review is to disseminate information concerning new developments and effective actions taken relative to the management of defense systems programs and defense systems acquisition.

The Review is designed as a vehicle to transmit, between persons in positions of leadership and responsibility in the program management and systems acquisition communities, information on policies, trends, events and current thinking affecting the practice of program management and defense systems acquisition. The publication serves as a means for providing an historical record of significant information associated with defense systems acquisition/management concepts and practices.

The Review supports the assigned mission of the Defense Systems Management College, and serves as a medium for continuing the education and professional development of persons in the field.

Review: US ISSN 0363-7727

DEFENSE SYSTEMS MANAGEMENT COLLEGE

The Review is an essential medium for communicating new ideas or restating of old ideas in the field of acquisition management. I have been impressed with the quality of each issue and intend to maintain that reputation. Thus I solicit comments from readers, both pro and con, so I know where to direct our efforts.

I believe it appropriate that each issue have a central theme so that the articles contribute to a specific acquisition area, rather than stand alone. To this end, Vol I, No. 5, will be devoted to Test and Evaluation with future issues covering Production, Development, Configuration Management, Software Acquisition and Management, Test Equipment Management and other important areas of the acquisition process.

Major General Jack Albert, my predecessor, made an outstanding contribution to the acquisition management process in establishing this Review and I look forward to carrying on the effort.

R. G. FREEMAN III
Rear Admiral, USN
Commandant

DEFENSE SYSTEMS MANAGEMENT

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Can Weapon System Procurement Be Managed

by

Albert J. Kelley, President
Arthur D. Little Program Systems Management Company

The complexities in the systems acquisition or procurement process for complex weapon systems causes many to throw up their hands and say that such programs cannot be managed efficiently—that delays and overruns will always be a part of the military-industrial method of doing business.

Must it always be so? Not necessarily, but the problem is so huge that it is difficult to grasp in normal management terms. Offered here by Mr. Kelley are suggestions that if adopted could perhaps alleviate the problem.

THE PROBLEM

Weapon system procurement problems have been well publicized. With increasing frequency, the media has reported schedule delays and cost overruns in such programs as the Trident Missile System, the F14 Fighter, and Navy Ship Construction Programs. Weapon system procurement, often called systems acquisition, comprises research, development, test and evaluation, production and delivery of complex technical systems that require many years from conception to birth and many more years to eventual maturity.

Schedule delays and cost overruns in such programs impact military effectiveness and national budgets and also have a subtle but serious effect on advanced research and development for Defense. In order to cover cost overruns on major programs with deep commitments, smaller advanced research and development programs are often reduced or eliminated. As a result, the long range potential of our Defense posture and future weapons systems is mortgaged to pay for the present.

Fortunately, some efforts are under way and other initiatives can be undertaken to bring weapon system procurement under sound management control. The problem does not defy description. It will take time, the efforts of many and, above all, strong leadership.

CAUSES—APPARENT AND REAL

Many causes are apparent for time delays and cost increases in major programs. Among those most often cited are technical problems, unpredicted inflation, and changing requirements. While these factors do, in fact, have an impact on weapons systems they are often symptoms rather than causes.

Too often, probing beneath the obvious symptoms reveals the real causes; management, procurement procedures, and their

handmaiden, decisionmaking. The industrial contractor usually bears the brunt for failure to make schedules and budgets but the government and its procedures are often equally and sometimes more at fault. The low man on the totem pole usually gets the blame when often the problem starts near the top.

The problems with weapon systems procurement and management often begin at the very initiation of the project. Insufficient mission analysis coupled with incomplete conceptual and technical definition can lead to poorly defined bid requests wherein the client agency is not completely clear what it wants, when it can get it, and how much it will cost. Decisions which should have been made before the contract was signed, are made eventually, but after a large work force is on the payroll and decision delays cost a lot more money.

Often, initial project cost estimates for completion of development or completion of a production run do not truly reflect all elements and are usually biased heavily on the optimistic side. A major cause of this phenomenon is the gauntlet of over 2 years from project initiation to receipt of first funding. In this period there are many hurdles and reviews, each step seeking to trim costs. At each review step, the project supporters face the choice of staunchly defending soft cost estimates against the risk of having the embryo project cancelled completely or yielding to pressures at each step to reduce further.

In this same time period, usually additional requirements are being added to the weapons system as more mission roles and more sophisticated technology requirements continue to be defined. As the project is being put together and before it has been funded, forces are at work trying to reduce the cost estimates while at the same time adding more capability, each of these factors acting in a contradictory manner.

No wonder some projects have an overrun built in at the start. The requirements are too complex and sophisticated for the government funds budgeted and requested. No matter what sophisticated management techniques are later employed, costs and schedules are doomed from the very start.

The problem of insufficient initial funding is compounded by the auction process that often goes on before contract award called "best and final offer." In this procedure, contractor finalists in the evaluation process are given the opportunity to make a final cost bid. The contractors are placed in the terrible dilemma of whether or not to destroy the credibility of their cost estimates, carefully conceived during the bid-response phase. Furthermore, the morale of the entire project team, both government and contractor, is affected if the contract is signed at a bid price well below what they themselves have developed as a reasonable range of cost parameters. The "best and final offer" procedures places the procurement process in the realm of a used car auction and runs directly contrary to the axiom "you get what you pay for." From the start this procedure acts as a force to build in eventual overruns.

As the project proceeds various routine approvals can often be delayed, causing costs to increase because a large work force is on the payroll. Approval delays can result from too detailed approval being required at too high a level within the Executive Department as well as Congressional delays where budget appropriations do not come through on the schedule anticipated in the original project plans.

Throughout the life of a project, the acquisition process is subject to many changes that cause delays, most of which in turn result in increased costs. Budget cuts, reprogramming of funds, increasing requirements and changes in scope or technical capabilities, tend to stretch out schedules and result in increased overall costs.

Continuity of management within a weapon system project is difficult to maintain. Not only do the project management staffs rotate, but the higher echelons within the Department of Defense often have an even shorter on-the-job life.

Because of military rotation requirements for career advancement, it is not in the best

interests of a military project manager to stay on the job too long. This is compounded by the fact that the project manager position does not itself represent an optimum career step in some of the military services. This is indeed paradoxical, for the weapons the military fight with are as important as how the military use the weapons and with how many people. Yet many capable military officers try to avoid project management positions because they feel these positions do not represent a step on the path to career advancement to the top. And in many cases, they are correct.

HISTORICAL REMEDIES

Historically, the Department of Defense has attempted to focus on different aspects of program management at different times. This has resulted in emphasis from time-to-time on concepts such as PERT, Value Engineering, Zero Defects, Management by Objectives, Design-to-Cost, and many other catch words and slogans. Too often management by slogan leads to overemphasis on one or two aspects of project management with resultant defocusing of attention on other equally important areas that can cause the project to fail.

In the course of a project, conscientious and intensive review processes are developed so that all echelons are aware of and can take action on the project and its management. In many cases over-management or, as it is often called, micro-management results. One sees micro-management of the contractor by the service and its project office, of the service by the Department of Defense, and of the project itself by Congress and the Government Accounting Office. The layers of intensive review lead to excessive reporting at all echelons. This results in an increase in man power, time, and costs.

Since the contractor has the implementation responsibility, most of the burden of this excessive reporting falls on his shoulders. This is in addition to complex control procedures already imposed in the contract so that the contractor can be monitored every step of the way down to the lowest level of work activity. Reports cost money and too often much information generated is not necessary or used.

RECOMMENDED SOLUTIONS

Many of these deficiencies have been recognized in recent years by key defense planners and managers. Many initiatives have been taken and need to be continued and reinforced. Additional steps will have to be taken as project management becomes more complex and as new Congressional and budget review procedures take effect. Some recommended actions are:

- **Require better initial planning prior to starting the weapons system procurement process through government channels which should eventually be reflected in the Request For Proposal.**

  Improved mission definition and analysis, coupled with clear cut technical requirements, scheduling, and budgeting should be accomplished during the conceptual stages of a weapon system procurement project.

- **Eliminate contract bidding auctions.**

  If the government project office determines schedules and cost ranges with confidence before initiating a Request For Proposal they are in a better position to evaluate proposals and insure the credibility of the initial contractor estimate in response to the RFP. With knowledge of the reasonable range of schedules and costs, the contract need not be auctioned off and ridiculous low-ball bids can be spotted immediately.

- **Good project managers are a key to successful weapon system procurement.**

  In this most important phase of overall defense management the project management position should be elevated to one of prime importance and distinction for career military officers. Military program managers should be able to stay on the job long enough to see a major phase of a project completed. These officers should be able to spend a major part of their career in project manage-

ment and still have an opportunity to succeed to the top positions in the respective service. The Defense Department has taken steps to provide education for project managers by founding the Defense Systems Management College. This institution was started by David Packard, then Deputy Secretary of Defense and has been encouraged since by his successors. The results of their efforts are already paying off, and the College should be given increased emphasis as it refines the curriculum and increases research capabilities.

- Faster and more orderly budget approval processes are needed in both the Executive and Legislative branches of government.

  The Congressional Budget and Impoundment Control Act of 1974 has many implications for weapon system procurement. More timely and long-range estimates are required by the Act that also defines deadline dates for Congressional fiscal approvals. As a result, longer looks into the future will be required from the weapons system project coupled with the promise of timely Congressional budget and appropriations approvals. Both factors will tend to increase project planning stability and may even lead to multiyear funding or, at least, earlier agreements on projects so that smooth development and production planning can be accomplished. This new Congressional Act imposes tighter, tougher schedules in the government approval process, forcing earlier decisions as well as longer projections.

CONCLUSIONS

There is promise that weapons system procurement can be managed more effectively and efficiently. Some initiatives and new concepts are underway. Much depends on how the new Administration continues and reinforces these initiatives and seizes the management reins to develop even better procedures and personnel.

There should be increased emphasis on improved, earlier initial planning using the best resources available within government and obtainable on a contractual support basis.

The requirement for advanced authorizations and early information to Congress under the Budget and Impoundment Act will place increased emphasis on high quality estimates over a longer time frame. This emphasis is advantageous but will increase the already heavy work load of the weapons system project office.

The key to future weapon system procurement success lies within the various echelons of the Department of Defense and the military services. Not only should DOD and the military services be manned with sufficient, well-qualified people, but they should be given full support, in-house and contractually to accomplish their important management functions and processes.

The focal point of future systems acquisition success or failure will lie increasingly in the military project offices. These offices should be given the capability, responsibility and authority to carry out the function of acquiring major weapons systems on time and on budget. □

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An educator and consultant, Dr. Kelley is the author of many articles and co-author of a recent book *Venture Capital: A Guidebook for New Enterprises.* Dr. Kelley is a member of the Board of Visitors, Defense Systems Management College.

A New Dimension
In the Acquisition Process

by

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In this article the author challenges the reader to think of the Defense system acquisition process from a perspective different from that which is customary. The questions asked are: "Has the solving of individual problems resulted in a piecemeal approach?" "Has suboptimization in selected areas been a major contributor to the long time lapse from program initiation to the fielding of equipment(s) the program was designed to produce?"

In the past 10 years there have been major efforts made to try to get a handle on weapons systems acquisition costs and risks and there has been considerable success in *both* areas. However, I am concerned that the approach to solving each of the individual problems that arose was perhaps too "piecemeal." Each problem was addressed with a "tailored solution" which, in fact, did tend to reduce cost in the specific area and did frequently reduce the risk at the same time. However, now it is time to step back and assess the *overall* acquisition process again. I submit that we may have "suboptimized" in many compartmentalized areas, and that we have not recognized the inherent conflicts and contradictions between and among these selected areas. The net effect, I fear, has been the current very long and very expensive overall process—the long time from initiation of a program to its deployment. It is to this latter problem that I call your attention.

In the past several years we have begun to recognize some of the inherent conflicts in the acquisition process, and to take some corrective actions. For example, in the past, performance and development costs were emphasized as the driving factors in weapons systems acquisition. When we were done, it was found that the systems developed were too expensive to produce in the necessary quantities, or too sophisticated and complex to be supported in the field. The need for designing in producibility at low cost in design-to-cost efforts, while at the same time embracing reduced operating and support costs goals is recognized. However, there is the inherent conflict between minimizing operating and support costs and maximizing readiness. Little is done in the development cycle today to explicitly address readiness. What is needed, and what we have begun to achieve, is the integration of a production and support *perspective* into the weapon system development phase of our programs. Clearly, this is *not* a case of giving something to everyone. In fact, tradeoffs must be made to achieve Defense objectives within the available resources. Thus, the last few percent of performance may have to be sacrificed for reduced production and support cost or improved readiness.

If one were to step back and look at the total acquisition cycle and the changes that have been brought about over the past 10 years, one could say that concurrency has been

*Adapted from an address to the Conference on Tactical Missiles, National Bureau of Standards, 27 April 1977.

largely eliminated and that significant steps have been taken towards reducing risks. However, we have *added:* "incremental decision-making," an increase in management reviews, considerable increase in test and evaluation, competitive prototyping, low-rate initial production etc. Each of these additions had the desired effect, but has also greatly increased the acquisition cycle time and cost. We have not removed anything! The effect has been that where we were able to field the NIKE AJAX in 6 years and the HAWK in 5 years, from requirement to deployment, it is likely to take 19 years to field the PATRIOT and 18 years to field the AEGIS.

Finding ways to compress the cycle without increased concurrency or risks is one of our most difficult challenges for the near future.

There are two major conceptual approaches that should be taken to address this problem. First, I submit we need to do much more early planning of the entire acquisition cycle. This includes the normal development cycle process, *and* the planning of alternatives, decision options, deviations from normal practices, acquisition strategies, industrial base impacts, production, maintenance etc.

Early planning includes considerably more "what if" planning; such that, when an event occurs we don't wait 6 to 9 months for the decisionmakers to evolve a plan for the next step. Early planning includes far more "key decision" points during the cycle. If significant achievements can be realized early, or if problems develop during early testing, new directions can be taken to minimize costs and time.

Secondly, I assert that far too much has been made of the *differences* between Defense acquisitions and commercial practices. A move in the direction of greater similarity would be extremely beneficial to the Department of Defense. The steps that we have taken over the past 2 or 3 years are steps in the direction of bringing military and commercial practices closer together.

Let me briefly cover some of these steps so that you may see some of the actions already taken in this direction, and so a better reference for the subsequent discussion on additional steps may be established. These additional steps are needed to specifically address the question of how to shorten the acquisition cycle.

INTEGRATION OF DEVELOPMENT AND PRODUCTION PLANNING

About 70 percent of our total weapon system acquisition and support costs are essentially determined during the conceptual stages of equipment development. Because of this it is imperative that the necessary kind of attention be focused at the front end of the process, to reduce "downstream costs." Some ongoing initiatives are discussed here.

First, more attention is being given to the initial stages of the acquisition process. As directed by OMB Circular A-109, entitled "Major System Acquisitions," the mission need is evaluated more critically and a wider range of available technologies to meet that need, quickly and efficiently–are considered both in terms of performance and life-cycle costs.

A major initiative is to improve and strengthen in-house production planning. It is ironic in a sense that although our production account varies between 65 percent and 80 percent of acquisition cost, in many cases the production community has no involvement until most of the parameters that influence these costs have been determined. The production community must become involved earlier in the systems acquisition process to ease the transition from development into production and to help reduce total cost. To accomplish this, we stress production planning assessments early in the development cycle, and urge early identification of manufacturing technology voids to aid the transition process.

In addition we are looking more to proto-

type *competition* for technological innovation—to obtain performance improvements, cost reduction and risk avoidance. I think we can use this tool more efficiently than we have. Significant, qualitative improvements from innovation are more likely to be found in the prototype development phase than during competitive production, where quantitative changes only are likely.

Design-to-cost is a commercial-product management tool used to help integrate the development and production phases. The concepts of design-to-unit-production cost and design-to-minimum-life-cycle cost are becoming institutionalized—goals are being established for both parameters early in the development cycle. Design-to-cost techniques have contributed to reducing the rate of noninflation cost growth of systems (as identified in our SAR reports to Congress) from over 6 percent per year in 1973 (when we were getting started), to around 3 percent today. The challenge is to keep moving in this positive direction as more flexibility and visibility is built into the management process.

The new Source Selection Directive is a major step in the direction of lower cost systems. This Directive states that development awards will be made based upon the inherent production and support cost of the proposed system—not primarily on the proposed development program cost.

Even though the Department of Defense has the responsibility of providing the "requirements" framework for new systems, industry's hands cannot be tied if lower cost systems are truly desired. We want—even during the bidding process—Request for Proposal (RFP) and contract changes recommended to us that will be cost effective. The new Source Selection Direction also takes a step in this direction.

A chronic complaint from industry has been that over-application of military specifications and standards drives costs up. Therefore, a major effort is presently underway to review all 40,000+ specifications and standards. The goal is to eliminate unnecessary specifications and standards and to update those that need it; but, most important, to allow and encourage "tailoring" to individual program requirements. Rather than starting by issuing directives that dictate the "scrubbing" of Requests for Proposals and the "tailoring" of specifications and standards, a considerable amount of missionary work was performed in this area. As a result, major programs such as HELLFIRE, the Navy Electronics Warfare Suite, and the F-18 have already tailored various requirements.

The objective is to get the Services to cause the necessary "cultural change" to take place, and I believe a good start has been made. The Services have issued some good "implementors." Based upon these efforts and other "lessons learned," an overall "scrubbing and tailoring" policy has been stated in the new DOD Directive 4120.21 entitled, "Specifications and Standards Application."

Just to mention some of the other initiatives for which new policy guidance is being issued: Commercial specifications are being adopted, greater use of commercial equipment and product warranties is being made, software is being standardized, and revitalization of the Value Engineering program is in progress.

Actions designed to improve the efficiency of our production process complement these cost reduction efforts. Manufacturing technology should be emphasized early, in concert with overall front-end production planning, to help bridge the gap between development and production. The manufacturing technology program has been redirected, to first identify production cost drivers that need attention; then to provide "seed money" to assist industry in developing innovative, and less costly, Defense production methods. Annual DOD funding in this area is being doubled—to over $200 million. A recent success story in this area is the GAU 8 ammunition—through a $3 million investment in a new manufacturing process, $300 million in production costs were avoided.

Another area to be attacked is the obsolescence of plants and equipment in the Defense industry. As a result of the "Profit 76" study

the DOD profit policy has been revised to reward needed investment by making, for the first time, the imputed interest cost of facilities an allowable overhead cost. Also, the weighted guidelines have been changed to provide increased profit based on company capital investment. Concurrently, other investment incentives are under consideration to encourage industrial modernization; these include greater use of multiyear contracting and special termination provisions to reduce risk.

To move in the direction of commercial practices, day-to-day involvement in the contractor's activities must be reduced. As a step in this direction, almost 2,500 people, who performed quality and contract administration functions are being removed from contractor plants.

On the industrial base side the idea of compartmentalizing, or suboptimizing, applies equally well. The past approach to conducting business with the Defense Industry has been to focus attention on specific cost elements at the prime contractor level. As a result, a "dual economy," with differing market characteristics, has been developed at the prime contractor and the subcontractor/parts-supplier levels.

For example, a joint DOD/OMB study of the US aircraft industry was recently completed. The chief findings were that this industry, at the prime contractor level, is operating at about 55 percent of one-shift capacity, and the cost of the idle capacity is conservatively costing the Defense Department on the order of $400 million per year. Similarly, it was found that "bottlenecks" for production "surge" rest primarily at the parts-supplier level—and this base is shrinking rapidly. Corrective actions have been initiated at both levels. The main point is that a broader perspective is being taken.

Similarly, where previous attempts were made to optimize the development timing and production rate for *each* program, we now look at the overall industry sector and firm impacts, and consider program timing and labor stability (e.g., the "constant work force" concept).

EARLY OPERATING AND SUPPORT PLANNING

The conflicts and challenges faced in trying to minimize the cost to operate the support equipments while improving force readiness are myriad.

I am sure that you have been made aware of the trends regarding the DOD procurement account. In the decade since the Vietnam peak, Defense buying power has experience a drastic erosion, going from a high in 1968 of $47 billion in outlays (in constant 77 dollars) to approximately $28 billion this year (1977), having bottomed out in 1975 at about $17 billion. Over that same period of time a significant growth in the share of the budget going for operations and support was experienced. However, even with the cost growth, readiness problems are experienced. Notable too is the fact that the interest of the Congress in the readiness of our military forces has picked up considerably over the past few months.

The Department of Defense is trying to do something about readiness, and simultaneously reduce the fraction of the DOD budget allocated to operating and support costs—a tough challenge!

Background: The Department of Defense spends approximately $14 billion annually to buy spares and consumables to support US operational forces. Even though Secretary Brown's amended Fiscal Year 1978 budget called for a net $2.8 billion reduction in other areas, more than $600 million was added back for readiness improvements. This approach alone cannot solve the problems. Long-term strategy must get the US back in the position where procurement constitutes a larger percentage of the budget than operations.

The DOD is working to get the parameters which impact readiness and associated operat-

ing and support costs defined early in the development cycle. From this, a cost-effective set of equipment design and logistics support alternatives which are consistent with our readiness goals can be developed. Also the DOD is looking at contracting approaches—e.g., warranties—to help make reliability and maintainability improvement happen. Clearly, followup is required to make sure that the goals are met. A radically new approach—a feedback or tracking mechanism that follows the equipment into deployment—may be needed.

SHORTENING THE ACQUISITION CYCLE

To return to overall acquisition cycle: While technological advances are occurring at a more rapid rate—as evidenced, for example, by the new families of tactical missile guidance schemes, the acquisition cycle is unnecessarily stretching. Programs such as LANCE and the TELEVISION MAVERICK were speedily concluded in about 4 years. Today programs such as COPPERHEAD and HARPOON may exceed 8 years. The DOD needs to look closely to see if this trend can be reversed—without increased risk.

Historically, the length of the acquisition cycle has been perturbated by two things—first, disagreement on what is wanted, and second, the tendency to bite off a larger technological chunk than we are capable of digesting. Circular A-109 forces us to resolve the first item, and Secretary Brown's recent policy statements emphasizing simplicity and reliability as weapon goals requires us to face squarely the second. Given these two steps, the decision process must be revised to take advantage of the potential for more rapid developments.

The risk, cost, performance and schedule tradeoffs required by the acquisition management process are difficult to make, at best. However, there are some definite steps that can be taken to achieve a better tradeoff balance, without undoing the positive things accomplished to date. First, a "hands-off" approach can be adopted during development for programs that do not have a high degree of technical risk. To make this work, two things have to happen—first, a requirements description and a test plan stating what is wanted must be provided. (Exclude the "how-to-design" specifications.) Second, a healthy competitive environment is needed to get innovative ideas and offset some of the DOD risk in this approach. The acquisition cycle benefits from reduced day-to-day management and suppliers have the flexibility to plan programs in the most time-efficient manner. This is the approach now being tried on the "Air Defense Gun."

Next, far too many programs that incorporate very high risk subsystems are presented for management approval. This procedure provides the framework for a vicious cycle of test and redesign between the subsystems and the carrier vehicles. Basically, more independent feasibility demonstrations of new components and new technology that will develop more options for weapon systems are needed. *Less* full scale weapon system development should be done. When technology is fully demonstrated, and then applied to a new system or a product improvement, costs are reduced by almost one-half.

For programs involving major technological advancements or uncertainty in operational acceptability, it has become normal practice in the last few years to develop and test hardware prototypes prior to entering full scale engineering development. The A-10, F-16, XM-1 tank, HARM and Imaging Infrared Maverick are examples. Perhaps ways to make more efficient use of prototypes should be considered. Obviously, if there are no technology advancements to be addressed, prototypes are not required.

If prototypes are used, they should be used so as to reduce the full scale development phase. The incremental addition of system requirements and demonstration objectives should be considered as the prototypes become stronger candidates to fill a particular mission need. With these incremental additions the overall cycle can be shortened. A start from scratch in the full scale develop-

ment phase would not be required nor would it be necessary to repeat successful tests.

The DOD prototype programs are structured as low-cost programs–minimum drawings, modified qualifications etc. As the prototype program evolves into a major contender, development activities can be modified, and production planning and producibility analysis can be instituted. At this point it may be possible to skip full scale engineering development and enter a low-level production phase.

Another fertile area for possible time savings is the time allocated for test and evaluation. The earlier testing begins the better; problems are found at a point in time when they can be solved with less cost and schedule impacts. Many of the programs today have separate and distinct contractor, developer and user test phases. Blending, or at least the sharing of test data can have obvious beneficial effects. This should in no way reduce the independence of test and evaluation–but it could result in significant time savings.

Another area to achieve time compression is part of the Manufacturing Technology Program; i.e., Computer Aided Design (CAD). The automotive industry states that CAD has reduced the development time for its cars from over 2 years down to 5 months. The belief is that design changes using CAD can be made relatively risk free. The transition from CAD to Computer Aided Manufacturing (CAM), using the same software, also contributes to a greatly reduced overall cycle. The CAD/CAM arrangement permits going directly from development into production. The challenge is to see if some of the CAD/CAM potential benefits can be shared by the Defense Industry.

An obvious shortcut in the acquisition process, and at low risk, is through improvements to existing equipment. Improved HAWK was a good step in this direction, as well as the new seekers for our air-to-air and air-to-ground missile series. In the future, the DOD may be forced to this approach for fiscal reasons as much as to satisfy the desire to field a capability at an earlier date.

North Atlantic Treaty Organization standardization is being given top priority attention. Here, the objectives are to improve force interoperability, make better use of total Allied resources, and lower costs of development, acquisition and logistics support. Allies of the US have made it clear that if standardization is to really work, it must not simply mean everyone purchasing the US systems. The Allies want the US to be open to purchasing their weapons. The DOD policy is consistent with the desires of our NATO Allies. The DOD will buy weapons developed by our Allies when these weapons meet US needs and are cost effective. The US will foster interoperability and standardization. Standardization, through the use of "off the shelf" foreign systems, offers both time and cost saving possibilities–if it's done right!

Also, the US, with a gentle nudge from legislation such as the Culver-Nunn Amendment, is considering codevelopment programs to achieve NATO standardization. A joint development program, between DOD and NATO Allies, would have reduced the acquisition cycle for joint programs such as ROLAND and AWACS. The US could have avoided the second development iteration evident in both cases.

A thought to consider on shortening the acquisition cycle is the concept of "parallel decisionmaking." Here, the idea is to have status monitoring of periodic and significant events and to issue incremental decisions–often based on "what ifs." The cycle length and the risk can be reduced by periodic releases, rather than waiting for major milestones that can be years apart. Incremental decisions would also eliminate the 6 to 9 months it often takes for decisionmaking at these "gates." The actions could be planned well in advance, so the incremental decisions and releases would be consistent with options contained in the long-range plans. The DOD is struggling with the "hows" of making this idea work. Your help and views on this matter are earnestly solicited.

There is no easy "cook book" solution to obtaining a good balance between risk, performance, cost and schedule in acquisition pro-

grams. To shorten the acquisition cycle, a variety of things can be considered; these include:

- Possible organizational changes to get our thoughts on a more aggregated level.
- A reconsideration of the decision making process toward more preplanned, incremental decision points.
- Changes in contractual procedures to provide stimulus for suppliers to furnish the best product in the shortest time.
- Through front-end planning to tie the process together.

SUMMARY

In summary, I suggest that the acquisition process has been approached in too much of a piecemeal fashion. Two necessary actions can help bring the total acquisition process back to proper perspective. First, through front-end planning, a more encompassing view must be taken toward optimizing the *complete* cycle. This forces a recognition of conflicts between subelements and promotes effective early tradeoffs. Secondly, we must apply policies and procedures which are more consistent with commercial practices—e.g., design-to-cost, "hands-off" competition, warranties and "tailoring" of specifications.

The problem is to translate these broad policies into workable, contractual agreements between the DOD and its industrial suppliers.

I have tried to provide you with some thoughts on DOD initiatives to improve the acquisition process. I have also provided you with some ideas on how an excessively lengthy acquisition cycle might be reduced, without increased program risk. This is the challenge I leave with you. Help us solidify our thoughts into workable concepts and then help us (DOD) implement them. □

Mr. Gansler is Deputy Assistant Secretary of Defense (Materiel Acquisition). Prior to this assignment he was Assistant Director of Defense Research and Engineering, first responsible for Electronics and later for R&D Planning.

Before joining the Office of the Secretary of Defense, Mr. Gansler was Vice President and Director of Business Development, Avionics Division, International Telephone and Telegraph Corporation. Earlier he held management positions with the Singer Company and the Raytheon Corporation.

Mr. Gansler has a B.E. from Yale University, an M.S. from Northeastern University (Electrical Engineering), an M.S. in Political Economy from the New School for Social Research and has completed his course work for a Ph.D. in Economics at American University. He has been an instructor in servomechanisms, and has published numerous professional papers.

Tailoring Program Requirements

by

William F. Brown
Program Coordinator

The author has engaged in the tailoring of requirements for proposals and programs during all phases of the program life cycle.

Most of the information presented in this article is based upon a paper that was sponsored by the author for the Technical Management Committee, Aerospace Industries Association. That paper included suggestions of all Committee Members. Thus, what is presented here represents an industry position on the subject. The information is consistent with published military procurement policies.

DECISION TO "TAILOR"

Department of Defense interest in the application of specifications and standards became manifest in November 1974. At that time the Defense Science Board was asked to establish a Task Force to identify the factors contributing to unnecessary contract costs arising from military specifications and standards. Appropriate action, to be implemented through Department of Defense (DOD) directives and instructions, was to be recommended. The Task Force consisted of both industry and military department executives. The Chairman was Dr. J.F. Shea, Senior Vice President of the Raytheon Company. An interim report of the Task Force prompted the then Deputy Secretary of Defense, W.P. Clements, to issue a memorandum for the secretaries of the military departments entitled "Specification/Standards Application." The memorandum was dated 4 August 1975. In this document Mr. Clements indicated that his staff had been instructed to initiate appropriate procedures, regulations and policies and to implement measures to correct the problems identified by the Defense Science Board Task Force. The memorandum specifically stated that specifications and standards should not be contractually invoked without a specific, coordinated "scrub and tailor" process.

The tailoring of requirements through the life cycle of a program, was recommended by the Task Force on Specifications and Standards of the Defense Science Board, and is now emphasized by both Government and by Industry. The military procuring activities have begun to actively promote tailoring and Armed Services Procurement Regulation, ASPR 1-1201, has been revised to reflect this interest. The tailoring of requirements requires consideration from the moment a need to perform an essential military mission is evidenced and the wherewithal to conduct the mission is first being thought about. At this time the process of sorting out specifications and standards, or portions thereof, that will eventually be applicable, begins.

DEFINITION OF TAILORING

The tailoring of requirements is an orderly process of sorting general military specifications into a specific set of requirements that when modified will be applicable to a certain procurement. General military specifications are available for innumerable products, services and documentation. The type of product selected to perform the mission is first taken into account. Next the phase of the acquisition cycle is determined and the end use of the item. The tailoring of the requests takes place in three steps:

- A gross selection of specifications/standards to be applied.
- Deletion of paragraphs containing requirements which are not to be applied.
- Adjusting the remainder of the requirements to suit the procurement and documenting the results.

Requirements (existing applicable specifications and standards) are arranged and collected in major categories so that they can be applied through the statement of work or suitable contract addenda to a request for proposal and to the eventual contract in an organized manner.

GENERAL PRACTICES

There have always been varying degrees of tailoring in all phases of system acquisition. Some requirements have been carefully tailored for use with a request for proposal but most have not. One example of an office that regularly performs careful tailoring is the Systems Criteria Branch of the Naval Air Systems Command. This office creates a type specification and proposed contract addenda for major categories of subjects to be applied to programs. Possibly other offices are equally well organized in this regard, but the typical practice has been to issue a Request for Proposal (RFP) with a wholesale collection of all the possible requirements applied in full. Many of the documents applied include references to lower tier specifications and standards whose application is not defined. The contractor is then faced with the problem of responding to the stated requirements even though he is virtually certain that a large percentage are either not necessary or are not applicable to the program phase. The subsequent contract award is the beginning of a sorting process to eliminate and adjust these requirements.

The sorting process can consume years through several program phases by continual negotiation and deviation. Meanwhile, the product is relatively unaffected as it wends its way to completion, largely oblivious to the paper shuffle that contributes little to its excellence but which detracts seriously from the mainstream of effort. The process is fraught with pitfalls, not the least of which is the lack of proper program task definition and the consequent lack of a firm basis for the program cost estimate. One major reason for this deficiency is the lack of a suitable method for organizing the requirements.

ORGANIZATION OF SUBJECTS

For a typical contract, most requirements can be said to fall within the following main categories:

- Product design requirements
- Management systems
  - Cost and schedule control system
  - Configuration
  - Assurance
  - Safety
- Test and demonstration
- Integrated logistics support
- Packaging and delivery
- Documentation
- Terms and conditions

The relation of the above can be seen in Figure 1. The relation of these items to a request for proposal and to a contract is nearly identical.

PERFORMING TAILORING

There are known means for tailoring requirements. The process requires painstaking work and organization. The level at which tailoring must take place is between the contract

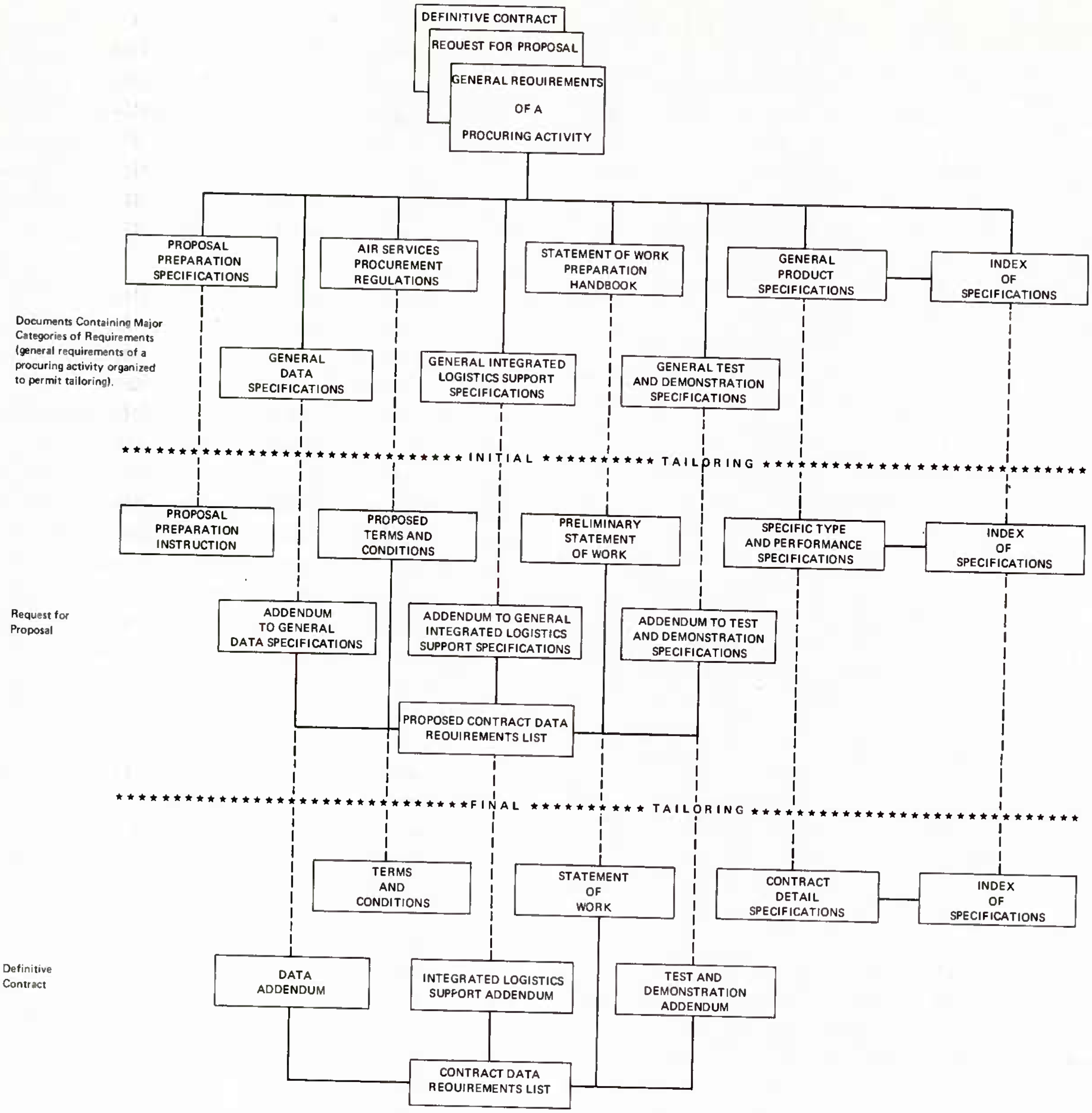

Figure 1. **Progression of Tailoring Process (from general requirements to contract for a typical procuring activity).**

level and the vast stratum of existing specifications, standards, handbooks and manuals written around every conceivable subject from chewing gum to complex firecontrol systems and complete aircraft and missiles: The DOD index has 75 on a typical page and the index contains about 550 pages. The process described assumes that every document mentioned, directly or indirectly, in the RFP is either in the possession of the contractor or is at least available to him for review.

Application of Documents

At least eighty percent of indexed military documents are inherently not applicable to any given procurement by virtue of subject alone. Some areas of procurement are even more fortunate. Propulsion devices for many years have had the applicability of specifications and standards limited to only an essential few by the issuance of a Government bulletin which, in effect, performs tailoring for a

particular product on a broad basis, and has been markedly successful in its application and use.

Limited Application

Some contractors have been successful in negotiating individual contracts in which the mandatory requirements were limited to the first tier of applicable documents. This allowed the remainder of the documents to be used as guides only and did not subject these documents to the specific deviation procedure. Rather than limit this approach to a few isolated applications, it is worthy of consideration for universal adoption.

Organization

Successful tailoring of a series of requirements documents for a procurement is an organized, thought-provoking refinement process. The process requires technical expertise and the best individual attention at appropriate levels of management. To insure adequate implementation, the process must be under the direct cognizance of the military and civilian program managers.

Existing Procedures

The success of the tailoring process requires that there be an existing vehicle at the level of application to a Request for Proposal or contract that can be adapted to the purpose. This vehicle can be contract addenda or a statement of work, or both. Reference to applicable military documents will benefit from the organization inherent in the use of the addendum and statement of work approach. Herein lies the key to the success of the entire endeavor. The tailoring is documented at this level and provides the tie between the general and detailed military requirements and the specific baseline for a given procurement. Documents and procedures exist for this purpose. New methods are neither needed nor recommended.

RECOMMENDED PROCEDURES

A detailed description of how one existing procedure operates on a regular basis is given here. The procedure is not new having been in use for at least 30 years. The procedure is not perfect but has been largely successful. The process involves use of six to eight documents designed to collect requirements in broad but related categories such as those mentioned under Organization of Subjects. The design requirements for the hardware are first tailored in a "type" specification that follows the format of an existing general specification. When used with the request for proposal, this specification provides a place to document the required missions and performance. Each part of the functional organization is privileged to provide input. The specification is then assembled by persons experienced in that work. Engineering data and development test requirements are developed and assembled in a similar fashion by the preparation of an addendum to a general specification made for that purpose. Demonstration requirements are tailored in the same way as are the requirements for management systems and logistics support. Data requirements are collected from these sources and listed on a Contract Data Requirements List. Thus the majority of the significant tailoring occurs prior to the request for proposal.

Ongoing Process of Refinement

The documents tailored in the manner described are transmitted with an RFP to prospective contractors. The documents are further refined by each contractor in his proposal that further tailors the requirements to a specific program and proposed system. Most contractors avoid drastic tailoring at this point for fear of being found nonresponsive. The Government must be encouraged to seek immediate ways to overcome this obstacle since tailoring at this juncture has the greatest potential for cost savings and cost avoidance. The requirements are refined still further to complete the predevelopment tailoring process during contract negotiation so that, at the time of contract approval, the documented results are available as contract attachments. This progression. and the relation of documents are shown in Figure 1. The process continues into the subcontractor/vendor/supplier relations.

Responsibility

The foregoing discussion has dwelled for the most part on tailoring of requirements by the Government. This is because the Government must perform the initial effort. Government personnel are organizing the solicitation and are dealing with Government requirements documents. In addition, the Government must have the requirements organized in such a fashion that the requirements are amenable to the tailoring process. After initial tailoring the contractor becomes more heavily involved. Ideally, the solicitation should contain language that encourages the contractor to propose cost effective waivers that are consistent with program objectives. Such encouragement must include language that clearly protects the contractor from being nonresponsive in the event that he proposes such waivers or changes to requirements.

Completion of the Effort

The majority of tailoring is not achieved until Full Scale Development is nearly complete. The need for many additional deviations and changes does not become apparent until the detail design is nearly complete and the program documentation is near completion. This final tailoring can be considerably facilitated by a good initial tailoring that forms a good base for the continuing effort.

Timing

The tailoring effort is influenced by the timing of the application of requirements. Premature application of specifications and standards can result in premature efforts to tailor such requirements. This situation is wasteful of time and money. Premature tailoring will result. The entire effort is fruitless and generally results in having to be done again at a more appropriate time based upon later knowledge.

Incentives

A good tailoring job is the mark of an able acquisition manager and is its own reward. The incentive to conscientiously perform a thorough tailoring may well be the receipt of a contract award in which case further incentives are unnecessary.

Extent of Tailoring

The tailoring described here is intended to achieve complete establishment of the applicability of primary Government documents at the contract application level, paragraph by paragraph where necessary. Reference documents are of less consequence than the primary or first tier documents and should not be made applicable unless they relate to a critical component, subsystem or related task. In such a case, the referenced document should be given primary document status and tailored for contract application. Otherwise the tailoring of referenced documents should not be necessary.

CURRENT STATUS

Industry

Industry agrees with the principles of tailoring that have been mentioned here. Industry knows from past experience that nothing fruitful will occur until the implementation of such principles is accomplished, until the process is made a part of the basic regulations, and until the principles are accepted at the working level and the process is made a part of regular practice.

Military Procuring Activities

- United States Air Force—Regulation AFR 800-3, entitled, "Engineering of Defense Systems" and dated 1 June 1976, gives the program manager the authority and responsibility to tailor requirements. Air Force Systems Command Regulation 800-25, entitled, "Application of Military Specifications and Standards to DOD Documents," requires that only essential specifications and standards be used and that they be tailored in application. The Aeronautical Systems Division is conducting training courses on tailoring of requirements. A contemporary electronics contract has a special provision that encourages the contractor to review military specifica-

tions and standards for the specific purpose of recommending exceptions.

- United States Naval Air Systems Command–AIR-510F, Systems Criteria Branch, has for many years successfully tailored major categories of requirements for application to solicitations and contracts.

- United States Army–Army Letter AMCRD-EM dated 13 May 1975 added the responsibility of exercising control over application of specifications and standards to the existing Data Review Boards.

- Department of Defense–Deputy Secretary of Defense Clements' 4 August 1975 letter stated that specifications and standards should not be invoked without a specific "scrub and tailor" process. Department of Defense Directive 4105.62 requires that a review board thoroughly examine requirements. This Directive 4105.62 provides for feedback from contractors either directly or through an industry association to eliminate unnecessary requirements from solicitations. Armed Services Procurement Regulations (ASPR) Case 75-135 recommends changing ASPR Clause 1-1201 to express minimum needs by tailoring the application of specifications and standards.

FOR THE FUTURE

The Defense Science Board Task Force, sanctioned by the Government, has recommended solution of this problem "by an immediate program throughout the Department of Defense and Industry to improve the climate of contractual application" and states, "the first step must be a joint government/industry effort to effectively tailor the contractual application of specifications and standards." The Defense Material Specifications and Standards Office (DMSSO) of the Office of Secretary of Defense for Installations and Logistics (I&L) will establish projects to carry out the recommendations of the Defense Science Board. The Technical Management Committee of the Aerospace Industries Association is prepared to establish comparable projects and furnish sponsors to interface with DMSSO. With Government and Industry dedicated to the successful establishment of the tailoring process, much progress can be expected in the foreseeable future. □

Mr. William F. Brown is a program coordinator and consultant. Mr. Brown retired from the Convair Division of General Dynamics Corporation after rendering 36 years of service. Primary assignments at Convair included duty as Specifications Group Supervisor, Chief of Data Control, Manager of Contract Technical Requirements and Convair Data Manager, and Project Coordinator.

Mr. Brown was the General Dynamics' representative to the Technical Management Committee of the Aerospace Industries Association and is past chairman of that Committee. This article is based upon material contained in a paper that he prepared on this subject at the request of the AIA Aerospace Technical Council. The article presented here reflects Mr. Brown's experience in the management of specifications, change control, data management, and contract technical requirements.

Mr. Brown attended the University of California at Los Angeles.

F^2D^2, *A System Management Tool*

by

Mr. Eugene Lurcott, RCA

A system engineering management tool that uses a proved technique is described in this article. The technique coordinates the interplay between system engineers and engineering specialists, and simplifies the attainment of a balanced system design in which each major design is based upon the proper coordination of system variables. These variables include such items as facilities, equipment, computer programs, personnel, training, testing, and intrasystem interfaces.

INTRODUCTION

The process described in this document assists in the definition, control, and audit of a balanced system design. This process enables translating the operational and system requirements into specifications, test plans, and procedures; and provides the backup data required to define, audit, checkout, and test the system.

THE TECHNIQUE

The Functional Flow Diagrams and Descriptions, F^2D^2, define and interrelate the functions of electronic equipment, mechanical equipment, computer programs, facilities, and personnel that constitute a system. The system is defined in user-imposed requirements, specifications, or other baseline documents. The F^2D^2 approach is a "top-down" functional analysis of the system, using an increasingly more detailed functional breakdown arranged in levels or "tiers." Each tier is a complete functional representation of the system at an essentially consistent level of definition. The implementation of the technique is embodied in Functional Flow Diagrams and Descriptions (F^2D^2) and in Sequence and Timing (SAT) Diagrams.

With the functional definition of the system complete, the functional response to any scenario within the scope of the system requirements becomes a subset of that definition. Linking the functions (at any one level of definition) in the sequence of use in the scenario results in what are called Sequence and Timing (SAT) Diagrams. Because the SAT diagrams arrange the functions sequentially, the cumulative system response times to the selected scenario can be indicated. Thus the SAT Diagrams can reveal if all functions are incorporated into the system to allow response to a given scenario and if the response times are within requirements. The diagrams also serve in the development of system test plans and procedures.

F^2D^2 DEVELOPMENT

The fundamental process of the F^2D^2 systems engineering tool is shown in Figure 1. The process ties into Military Standard 490 which sets forth practices for the prepara-

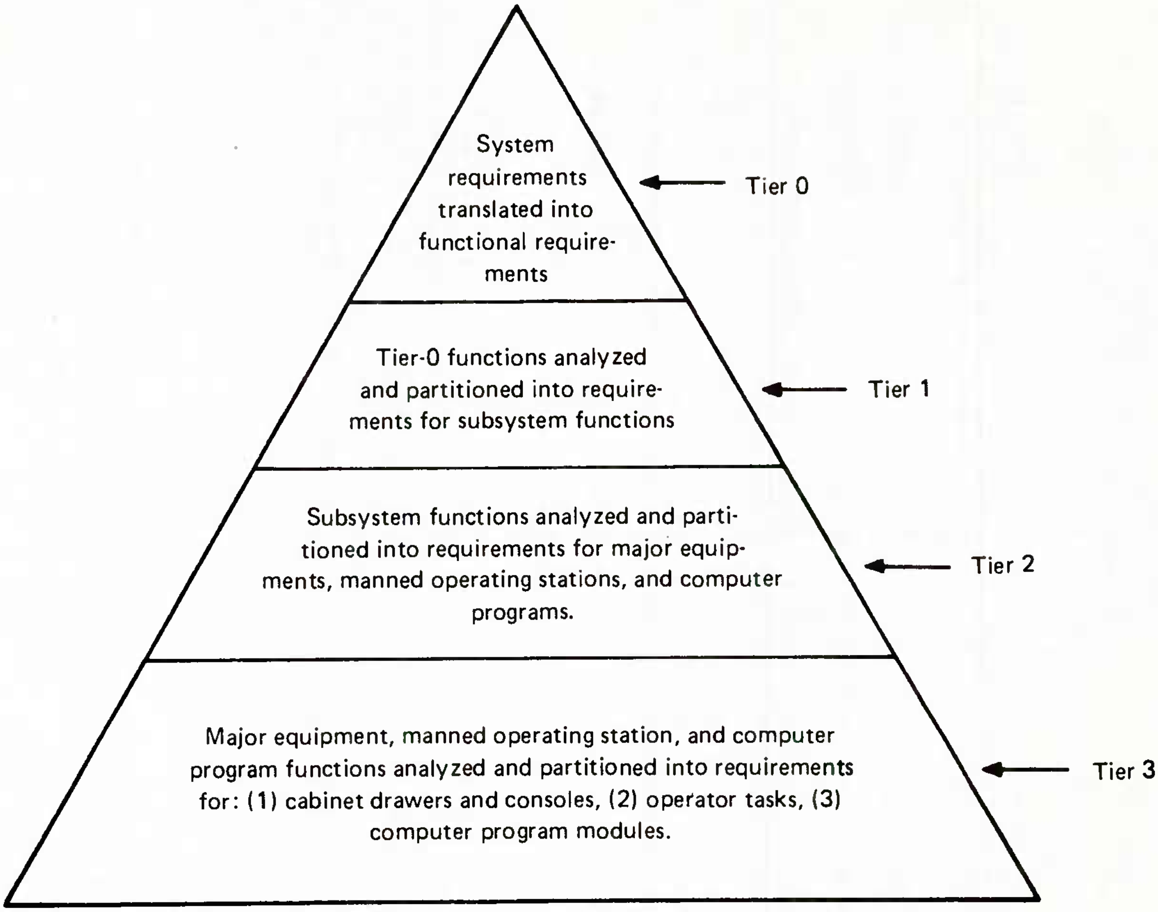

Figure 1. The Four Tiers of the Functional Analysis (F^2D^2) Process (a top-down approach for total system definition).

tion and interpretation of program-peculiar specifications prepared for military use.

Tier-0 F^2D^2

The first step in the F^2D^2 process is initiated by identifying the system requirements. (See Figure 2.) These requirements may be contained in top-level work statements, specifications, or other baseline documents. The requirements are translated into functional requirements, i.e., statements of operation. These operation-oriented requirements are presented in the form of a top-level (Tier-0) functional flow diagram. The number of Tier-0 functions into which the system is divided is governed by functional complexity. In most cases, except for "Input Interface" and "Output Interface," the function titles are self explanatory. All inputs to the system come in through "Input Interface" and all outputs from the system leave through "Output Interface." This procedure aids in accounting for all external interfaces and also bounds the system. As in all F^2D^2 diagrams, inputs come in to the left, and outputs leave from the right. At the Tier-0 level, data paths are limited to basic, high-level information sufficient to show how the functions tie together.

When applied to definition of a Department of Defense procurement, the Tier 0 of the F^2D^2 is used for paragraph 3.1.4 "System Diagrams" of the Type-A System Specification as defined in MIL-STD-490. This paragraph incorporates the system-level functional schematic diagrams, shows the top-level functional flow diagram of the system, and documents the abstractions of the functions.

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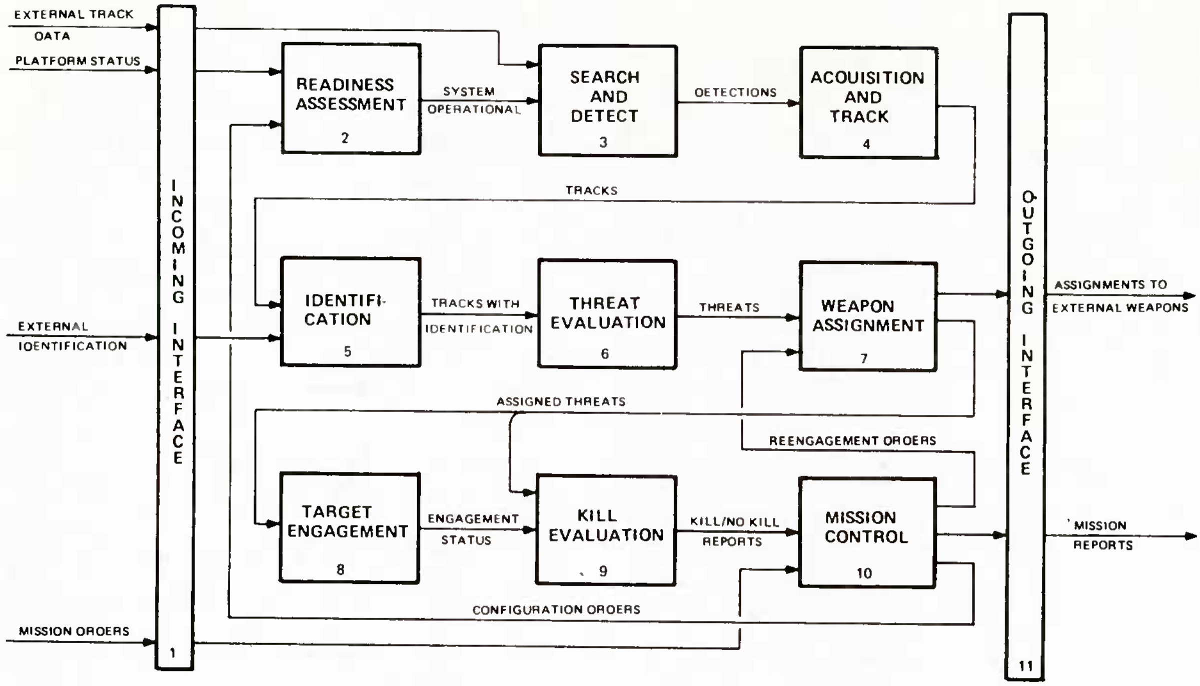

Figure 2. Example of a Tier-0 Functional Flow Diagram.

Tier-1 F^2D^2

Tier 1 represents the second step of the F^2D^2 process. In this step, top-level (Tier-0) functions and the associated criteria are analyzed and translated into design requirements to be allocated to specific elements (subsystems) of the overall system. At this point the significant characteristic is a functional definition and allocation of these functions to segments. Figure 3 is an example of a Tier-1 diagram. In Figure 3 one of the blocks in the Tier-0 diagram, Figure 2, is detailed.

In general, each block in a Tier-0 F^2D^2 results in a separate sheet of the corresponding Tier-1 F^2D^2.

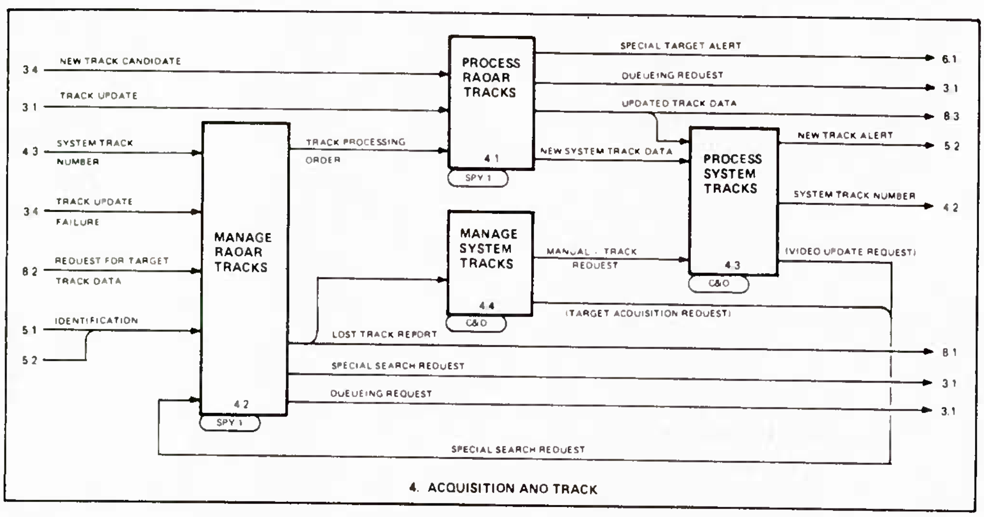

Figure 3. Example of a Tier-1 Diagram. (The "4" in the title refers to Block 4 in the preceding diagram.)

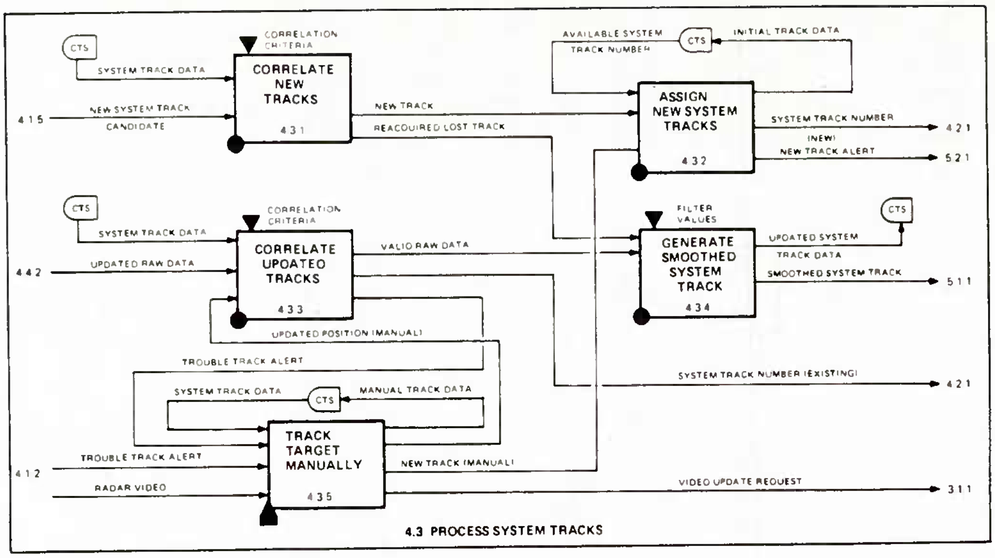

Figure 4. Example of a Tier-2 Diagram. (The "4.3" refers to Block 4.3 in the preceding diagram.)

At the Tier-1 level, implementation of the functions is not addressed. Thus whether the Tier-1 functions are to be performed by personnel, by equipment, or by computer program is not considered. What is addressed is the division of the Tier-0 functions into the Tier-1 functions necessary to perform the various tasks (e.g., data acquisition, analysis, decisionmaking, and control). This division into functions enables defining the critical data paths and the interrelationship between the Tier-1 functions.

Another important part of the Tier-1 step is the systems engineering studies which are performed concurrently with the functional analysis to: (1) select from alternate choices of function sequences, (2) determine the best system design approach, and (3) trade off among choices of element allocations.

Tier-2 F^2D^2

The next step in the F^2D^2 process utilizes the design approach determined from the systems engineering studies and the Tier-1 functional design. The element functions are analyzed in sufficient technical detail to allow the allocation of the Tier-2 functions to: (1) equipment, (2) computer programs, or (3) personnel. Figure 4 is an example of a Tier-2 diagram. Note that one of the blocks shown in Figure 3 is detailed in Figure 4.

The Tier-2 step also includes element studies which are performed concurrently with the functional analysis to: (1) determine the design, personnel, training, and procedural data requirements imposed by the function, and (2) select the optimum design approach for integrating the design requirements into the Prime Item Development Specification (B1) and the Computer Program Performance Specification (CPPS) for the element.

Tier-3 F^2D^2

In those areas of the system requiring more detail than was developed in Tier-2 analysis, a Tier-3 F^2D^2 may be required. Based on the functional analysis and element engineering studies performed in Tier 2, the functions are analyzed in great detail and are translated into operator-task requirements, hardware-design requirements, and computer-program design requirements. Figure 5 is an example of a Tier-3 diagram.

Performed concurrently with the functional analysis are design studies aimed at optimizing implementation of the functions allocated to equipment, computer programs, and operator tasks. These design studies and analysis result in the support of full definitions and descriptions of the functions in the appropriate specification, i.e., type B-2 speci-

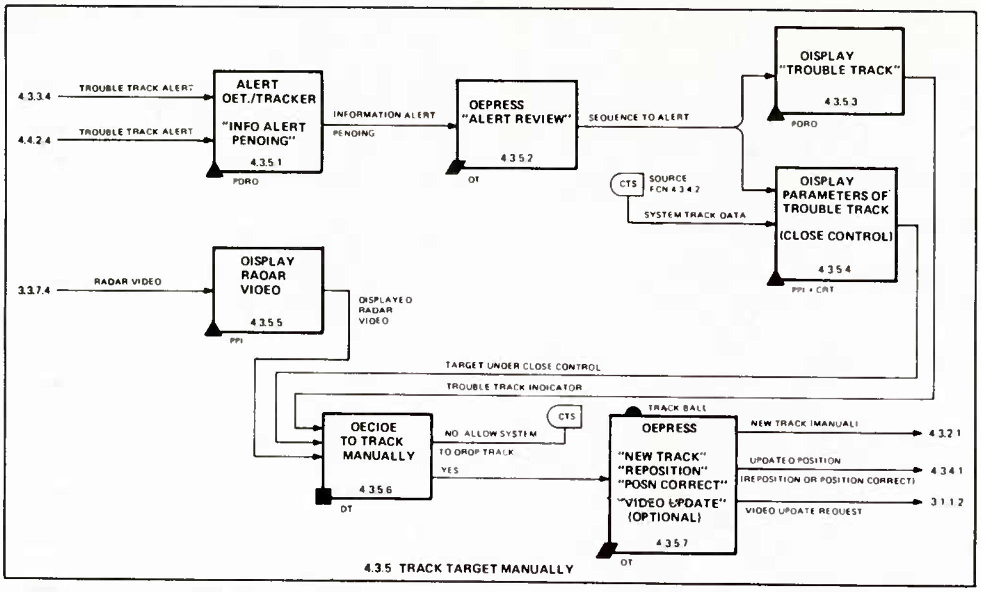

Figure 5. Example of Tier-3 Diagram. (The "4.3.5" refers to Block 4.3.5 in the preceding diagram.)

fication for critical item development (performance) and computer program performance specifications. The studies also support non-specification documents such as man-machine interface documents.

PREPARATION OF FUNCTIONAL FLOW DIAGRAMS

Functional Flow Diagrams are prepared in the same manner as other engineering sketches and serve to translate system requirements into functional terms. Accuracy and completeness of the diagrams are more important than format. However, to avoid misunderstanding, certain conventions and symbols have become standard. The rules and basic symbology for the diagrams are discussed below.

Functional Definition and Numbering

A function is defined not by a name but rather by the input data upon which it operates and by the output it produces. All functions are represented by rectangular boxes. These boxes may be visualized as "transfer functions" in which input data are operated upon to give output data.

Functions at each tier are numbered in a manner that preserves the continuity of the functions and enables tracking the functions through the system. Functions at a top level (Tier 0) are numbered 1,2,3,4, etc. Sub-functions of these top level functions contain the same parent identifier and are coded at the next decimal level. For example, the first indentured function (Tier 1) of function 3 would be 3.1, the second indenture (Tier 2) 3.1.1, etc.

For expansion of a function within a particular level of indenture, a numerical sequence is used. For example, the numerical sequence used to amplify function 3 at the Tier-1 level would be 3.1, 3.2, 3.3, 3.4, etc.

Experience has shown that each tier should amplify the definition of the higher level function approximately 5 or 6 times. However this will vary with the complexity of the function being amplified.

A basic ground rule of F^2D^2 is that different tiers do not appear on a single functional flow diagram. That is, the output of a Tier-1 function is not the input of a Tier-2 function. Tier-1 functions talk only to each other, just as Tier-2 functions talk only to each other.

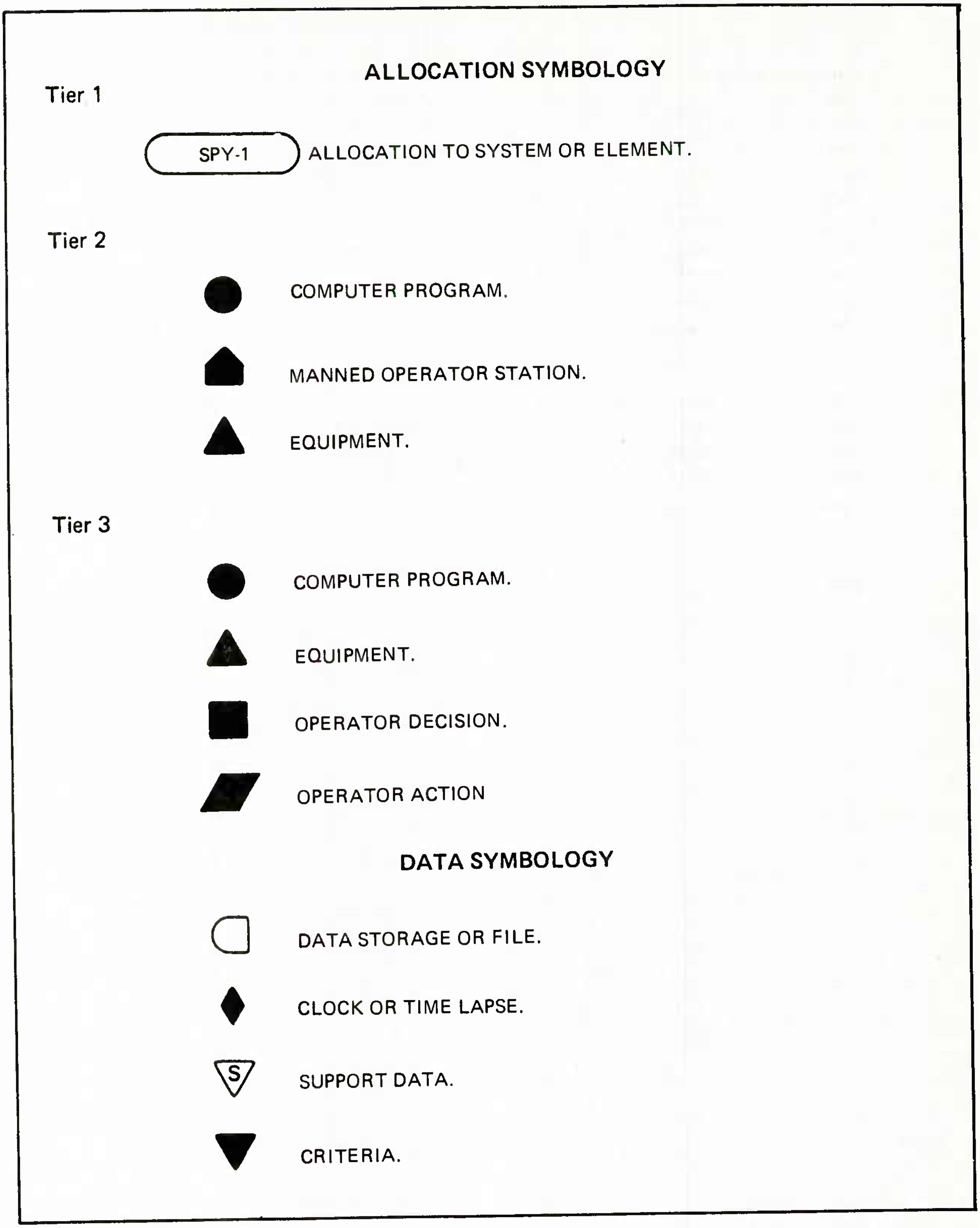

Figure 6. F^2D^2 Symbology.

Data Flow

Lines connecting functions indicate the functional flow and do not represent either a time lapse or any intermediate activity. Numbers at the end of the lines identify the source or destination function for the data. If possible, input data enters a function at the left, and output data exits the function from the right. A true functional analysis will include the feedback involved in the system operation. In the flow diagrams this is accomplished by looping the data around the functions involved.

The functional flow across interfaces enables the mutual audit of both functions and interfaces, thus ensuring that both are complete, compatible, and in accordance with specified requirements.

SYMBOLOGY

As shown in Figure 6, there are two classes of symbology used in the functional-flow diagrams. One class is used to indicate the functional allocation, and the other class is used to represent different types of data source or data sinks.

Allocation Symbology

Allocation symbols are located at the lower left corner of the function box and are used as follows:

Tier 1—Allocations of functions at the Tier-1 level are to major subsystems or elements. These allocations are shown as subsystem or element initials in an ellipse.

Tier 2—Allocations of functions at the Tier-2 level are to computer programs, manned operator stations (an operator in conjunction with a console or panel), or equipment. A function allocated to a computer program is represented by a solid circle. A function allocated to a manned operator station is represented by a solid pentagon. A function allocated to equipment is represented by a solid isosceles triangle.

Tier 3—Allocation of functions at the Tier-3 level is to specific computer program modules or algorithms, operator tasks, or specific equipments. These are represented as shown in Figure 6, with the specific implementation notated as operator initials, computer program label, or equipment name.

Data Symbology

Data symbology is also shown in Figure 6. Frequently data generated by one function is used at a later time by another function. This storage of data is shown on the flow diagrams by a "file" symbol. These "file" symbols represent the complete spectrum of types of data storage required in a system, ranging from high speed (e.g., magnetic core memories), to very low speed (e.g., grease pencil on a plot board).

The performance of some functions is controlled by a clock or time lapse. This time lapse is represented symbolically by a diamond located at the top of the function.

Many functions require support data to allow the function to perform. Support data are defined as the type of data that neither initiates the function nor dictates how the function operates. Examples of support data include displayed data, ship speed and heading, special intelligence. Support data usually vary during the mission and are portrayed by a triangle with an inscribed "S".

The last type of data used by a function is criteria type information. Criteria data are defined as that data that establish the boundary conditions, thresholds, limits of operation, priorities, etc. Criteria data define the constraints within which a function can perform. Criteria inputs are presented by closed triangles at the top of the function. The criteria are identified by name or generically.

FUNCTIONAL DESCRIPTIONS

The Functional Flow Diagrams may be considered as system "road maps" at progressively deeper levels of detail. Accompa-

FUNCTION NAME: Process System Tracks FUNCTION NUMBER: 4.3

ABSTRACT:

This function initiates and maintains automatic system track processing. It also implements manual track.

Incoming Data	Outgoing Data
New System Track Data	New Track Alert
Updated Track Data	Smoothed System Tracks
Manual Track Request	Video Update Request

CRITERIA:

This function implements automatic track processing by operating on radar data received in digital format and implements manual track by operating on radar video.

Automatic track processing includes initiation of the track file in the Central Track Stores (CTS), for each new track that enters the system, generation of smoothed position and velocity data from update data and predicting the track position at a subsequent time. Each New System Track candidate is spacially correlated with tracks in the CTS to avoid initiating new tracks for lost tracks reacquired by the radar. Reports which represent Reacquired Lost Tracks are processed as track updates. Reports which do not spacially correlate are processed as New System Tracks. A System Track Number (STN) is assigned and forwarded to the radar and the track smoothing filter (α, β filter) is initialized.

Processing of each track update report begins with a check for presence of a System Track Number (STN). Track reports that do not include an STN occur when the radar has updated a track before it associated the STN with its track data. Track reports that include an STN are correlated with the CTS track data via STN; track reports that do not include an STN are correlated with the CTS track data via the radar track number. The processing that follows correlation includes estimation of smoothed position and velocity by means of the α, β filter, predicting position of the track at the expected track update time and forwarding the data to the Identification Functions.

Manual track is initiated by decision of an operator. The operator ball-tabs a location on a display (near which he has reason to believe a target of interest is present), and requests a video update. When the requested video appears on the display he ball-tabs the video and depresses the "New Track" AEB. This initiates manual track processing. After a reasonable time lapse, the operator requests another video update. When the requested video appears on the display he hooks the manual track and depresses the "Position Correct" AEB. This produces processing which generates smoothed position and velocity and the predicted position at the next update (the next expected video update request). This process is repeated until the operator decides to either designate the track for automatic processing or to drop the track.

ALLOCATION:

This function is allocated to Command and Decision. The automatic and manual track requirements for this function are allocated respectively to paragraphs 3.4.1.2.3 and 3.4.1.2.4 of the WS 123456 specification.

Figure 7. Example of Functional Description which Accompanies each Block of a Functional Flow Diagram.

nying each function block at each level is text material giving a functional description of the particular functions. Figure 7 is used as follows.

Abstract

The abstract is a concise description of why the function is in the system, and what it does.

Incoming and Outgoing Data

The incoming and outgoing signals and/or other data is listed here in greater detail than can readily be depicted on a flow diagram.

Criteria

The criteria is the major section of the functional description. How the function operates on the inputs to obtain the outputs, at a level of detail governed by the tier level of the particular functions is described here. If required for complete understanding of the operation of the function, formulas and limits are included.

Allocation

This is an extremely important section that identifies the specification(s) and/or other design document(s) and the particular paragraph(s) within each such document that specifies the function. This cross-reference enables a complete system audit by making all functions traceable to approved documentation and all documentation traceable to allocated functions.

SEQUENCE AND TIMING DIAGRAMS

A useful adjunct to the basic F^2D^2 is the Sequence and Timing (SAT) Diagrams. A SAT Diagram is a scenario-oriented "needle and thread" pass through the F^2D^2. A SAT Diagram uses the functions tied together in the same way as in F^2D^2, but with only the inputs and outputs applicable at that function of the scenario.

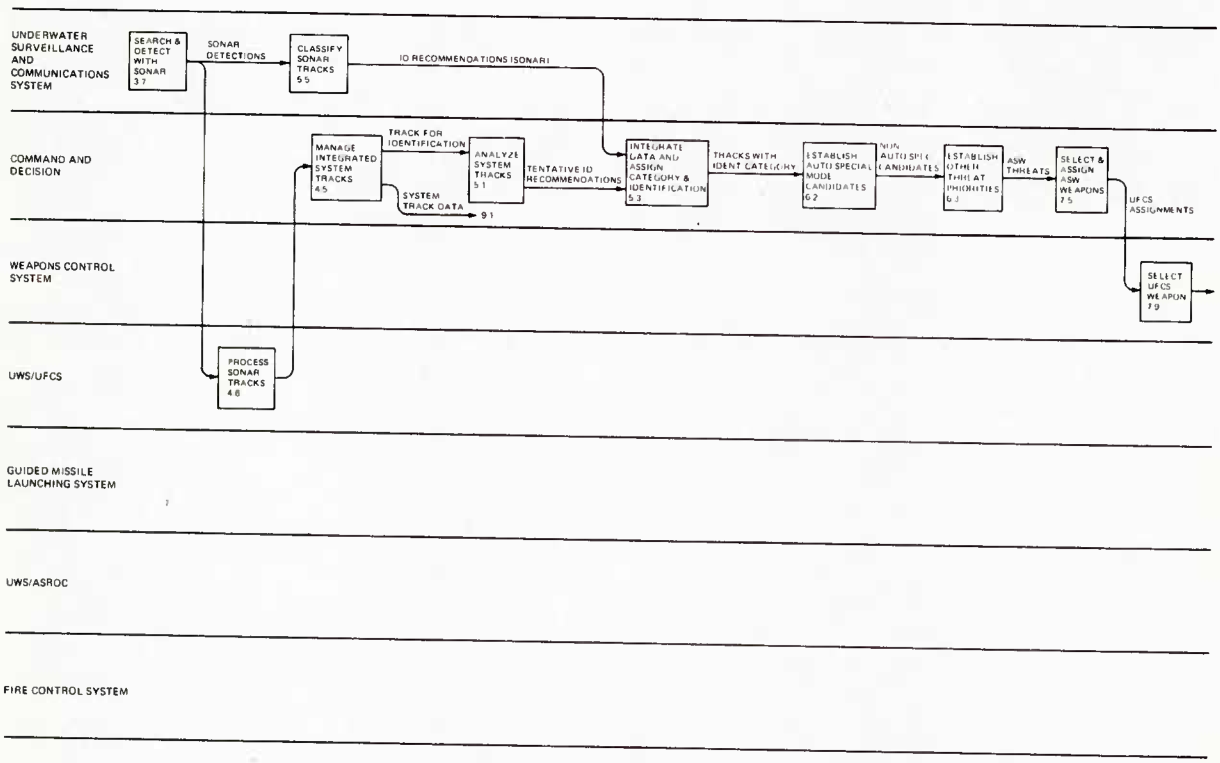

Figure 8. Part of a Sequence and Timing Diagram (SAT).

The SAT Diagram links, in serial form, the functions involved in any particular system usage scenario. Thus the diagram is helpful in predicating the response time of the system to that scenario. Moreover the SAT diagram is helpful in system test planning to ensure that all system functions are exercised. SAT diagrams tend to be large; Figure 8 is a rudimentary example.

SUMMARY

F^2D^2 is a systems engineering management tool that provides a complete function definition of the system under development. The F^2D^2 translates the missions, goals and requirements of the specifications into functional diagrams and functional descriptions for every level of system operation. As a tool for system definition, F^2D^2 provides the baseline from which all functions are quantified and allocated. As an auditing tool, it provides the visibility required to ensure that all functions have been incorporated in the design and that the design is in accordance with the system specification. Design control is supported through the combined use of definition, audit, and the associated functional descriptions.

Because of its proved value in the development of the first AEGIS engineering development model, F^2D^2 is being used in the design and development of the AEGIS Ship Combat System. In addition, F^2D^2 is being imposed on programs throughout RCA. □

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Observations on Defense Acquisition

By

Dr. Joseph F. Shea, Raytheon Company

Research and development requires an effective atmosphere in which to flourish. Elements that contribute to the creation of useful products include:

- Consistent commitment to reasonably defined goals,
- Balanced design,
- Technical and management disciplines,
- Recognition of uncertainty,
- Product follow through by the developer, and
- Experienced people and well defined organizational relations.

In this article the author provides an assessment of present Department of Defense (DOD) acquisition practices, as related to these elements, with a view toward possible improvements.

GOALS

The goal of those charged with DOD acquisition is to equip the US Armed Forces to assure a military capability superior to that of any potential enemy. But such a statement is too general to be useful. Superiority must be translated into how many of what things are to be developed and procured. Complex issues, ranging from the present and projected capabilities of potential enemies to the roles of the individual services, are explicitly interwoven with the process of setting requirements. By the time a specification for a new piece of defense equipment is ready for procurement it has been shaped and constrained by many detailed choices involving mix of forces, types of weapons systems, mechanization of subsystems and availability of technology.

There is a danger that our mathematical ability to analyze and simulate can create the illusion that requirement generation is a science. The fact is masked that as requirements generation pits conviction against compromise, and quantity against performance, it is a controversial process much closer to art.

The questions at all levels have more than one possible answer. Study team after study team purports to derive the correct solution where, in fact, any one of several available options could be equally acceptable. Inevitably, since there is no one right answer, the decision becomes a function of the experience and personality of the decisionmaker. Fortunately, several almost equally acceptable options usually exist, so the problem is not one of making "the right" decision. Because of the ever larger number of people with diverse background who are involved—within a service, within the Department of Defense, and increasingly within Congress—the decision process has become very long. When the

mean time to decision begins to approach the tenure of the decisionmakers, instability or paralysis can result.

Consistent commitment to reasonably defined goals requires continuity of personnel and a recognition of the imprecise nature of initial requirements. The implication for defense acquisition is a longer tenure for key decisionmakers, and greater flexibility to adapt requirements to the reality of development.

The results possible through continuity of key personnel and organizational structure can be dramatic. Examples include the consistent achievements, over more than 2 decades, of the Fleet Ballistic Missile Program and the Navy Nuclear Propulsion Program. Other areas of potentially equal importance, but without the continuity of leadership have made little progress despite the fact that applicable technology is not a limitation. To emphasize the point still further, transformation of the Russian Navy was accomplished during the 20-year tenure of Admiral Gorshkov as Admiral of the Fleet of the Soviet Union.

Increased performance in a weapons system usually means a higher price. Within the constraint of DOD budgets, higher price per unit translates into fewer units. Thus the articulation of requirements directly impacts the affordable force structure. Historically the problem has been compounded because the requirements, once established, were considered fixed. Developments complied—or only belatedly challenged the requirements after protracted problems had shown the requirements to be impractical. In either case, the emphasis on performance frequently resulted in higher than planned production costs forcing reduced operational quantities.

The most promising antidote for this historic malaise lies in the philosophic principles behind the "design-to-price" approach to contracting which is beginning to be accepted within Defense Acquisition. The Government establishes a unit price for a new equipment, along with a range of acceptable performance. The development team is challenged to provide the highest performance (balanced across a number of parameters) for the stipulated price. The contractor must use production cost, in addition to performance, as a major design constraint, and the Government is forced to recognize the inevitable interdependency of performance and cost. Effective implementation of design-to-price can be a major factor in checking the escalation of defense equipment costs.

BALANCED DESIGN

Research and Development activities exhibit two characteristics which seem to be almost universally true:

- The output of a design organization usually improves with each iteration. The initial design cycle rarely approaches what can ultimately be achieved in performance, reliability or cost.
- The first applications of new technology are always accompanied by unexpected problems. The gains in performance, size, weight, or cost are initially bought at the price of development delays, performance short falls, low production yields or unexpected operational problems.

A corollary is that effective development involves evolutionary improvements in products by experienced design teams. New technology should be introduced only where the payoff is significant. In other words, successive generations of equipment should use what has been proved from existing design, and stretch the "state of the art" only where new technology is mandatory to achieve the goal.

The commercial world is replete with examples—the telephone system, automobiles, appliances—where the successful organizations steadily evolve their product, and the less competent fall by the wayside.

How does DOD, who is the only customer for a wide range of products, handle this issue?

With notable exceptions, continuity is provided more within the Government Laboratories than within contractor organizations. In principle, each procurement for a new generation of equipment stands on its

own, equally available to all comers since "all contractors are created equal." Too often, the assumption seems to be that proposals alone provide a sufficient data base to accurately select the best qualified contractor. The fallacy in that assumption can be judged by observing the number of procurements in which technical normalization is forced on the bidders, until the competition ultimately becomes a price auction. When this happens, particularly with cost type procurements, the experienced contractor is at a disadvantage, since he knows both the product and the customer in detail. When cost becomes the major evaluation criterion, realistic bidding is discouraged, and the door is opened to either deliberate buy in or inexperience.

Perhaps of even more concern is the question of what influences the procurement specifications. The Government in-house laboratories are technically oriented and tend to display the proclivity of most engineering organizations—an attraction toward new technology. This trend is exacerbated by contractors who attempt to create competitive advantage by convincing the preparers of the Request for Proposal that the fruits of their advanced development programs are ready to be plucked. Individual contractors usually emphasize different aspects of a system, and it is all too easy for resultant specifications to reflect a spectrum of technology which no one contractor can comfortably encompass, and which is not really required for the mission.

There is an old proverb which can be traced back through Voltaire to the Greeks. "The better is the enemy of the good." Too often we obsolete an existing "good" for a presumed "better" only to find the benefits illusory and the cost exorbitant. A new system does not have to be composed of all new subsystems. Aircraft can use existing communication or guidance systems, radars can use existing displays—the list can be quite long. At lower levels, the use of standard parts that have a production pedigree and are understood by designers can lessen development risk, while at the same time simplifying future logistics.

A few segments of the Defense industry do operate in this fashion. The development of aircraft engines has devolved to only two companies and new developments are the result of carefully nurtured product improvement and advanced technology programs. But in many sectors the Defense industry is over expanded. The emphasis is on technical innovation as a road to survival. Jacques Gansler's study of the DOD Industrial Base shows both over capacity at the system level, and atrophy of capability at critical subsystem or component levels.

Although greater emphasis on relevant experience in procurement might be viewed as potentially limiting to competition, in reality it would bring DOD much closer to commercial practices in which the re-procurement actions of satisfied customers are a major factor in the free enterprise "survival of the fittest."

The present situation in Defense Acquisition may be the result of a failure of presumably free enterprise policies (competition open to all) in a monopsonistic environment which is unable to generate clear cut criteria to select superior products. Indeed, the excess of capacity in some areas and the dearth in others may eventually dictate more consciously planned management of the industrial base than DOD has practiced in the past.

DISCIPLINE

One of the greatest pitfalls in Defense Acquisition is a combination of inflexibility and overkill. Research and development management requires discipline across a spectrum extending from detailed design through cost and schedule control. The DOD procurement structure is interlaced with requirements for formal procedures designed to achieve such discipline. These requirements have been mandated by successive administrations that tend to view the recurring acquisition problems—overruns, schedule slippage, costly and unreliable hardware—from somewhat different perspectives. There is a tendency to generalize a DOD-wide solution from the specific experience on a given program. Often a new set of requirements is introduced without

modifying existing practices. The result is a redundant set of checks and balances so encrusted with refinements that the rigor sought comes closer to rigor mortis.

Take, for example, the introduction of Independent Operational Test and Evaluation as a major check on the development process. This check represents a significant and positive step—a step needed because, despite the apparent rigor of qualification testing, reliability testing, maintainability testing, et al, the resultant operational hardware too often has been unsatisfactory. In addition to independent evaluation, operational testing provides a realistic environment for the collection of reliability and maintainability data. Yet programs continue to incur the delay and attendant cost of dedicated reliability and maintainability tests in series with Indepenpendent Operational Test and Evaluation.

Might it not make more sense to consider all tests relevant to the assessment of the reliability potential of new equipment? In particular, the logs from both developmental tests and Independent Operational Test and Evaluation should provide sufficient data to assess the mean-time-between-failure and the mean-time-to-repair of the equipment under test. In addition to saving time and money, the test conditions would be more realistic than present practices.

Effective checks and balances should stress content, not form. But the continued refinement of a discipline can often lose sight of the original intent. Again, consider *reliability*. The elements that produce a reliable product are conservative design, consistent derating, and pedigreed parts coupled with a rigorous test program that, in the limit, identifies and fixes the cause of every failure. When failure follow up is continued through initial field experience, reliability can be expected to improve over the early years of product life.

Most reliability programs stress independent review of design for reliability related matters and the use of high reliability parts. The programs also require a relatively long test program, conducted under somewhat artificial conditions, that is designed to assess (with statistical significance) how close the hardware comes to meeting its mean-time-between-failure specification. The tests are usually carried out on developmental hardware that may earlier have been used for qualification testing, or on early production units that may not be representative of the operational population.

Although mathematically elegant, statistical significance is probably the least significant element in achieving reliability. In the Apollo Program, usually credited with being the acme of reliability, it was concluded (after the conventional approach to reliability had been followed for a few years) that statistical reliability assessment was both impractical and unnecessary. Rigorous ground testing and failure follow up provided the technical and management confidence to man rate the Saturn V booster after only two unmanned launches; one to be sure that the flight regime was as expected, and the second to be sure the first was not a random success.

While it is true that quantities in DOD procurements are larger and therefore more susceptible to statistical analysis, the real reliability data lies in the failures encountered in development and operational test programs, and in the experience with deployed field equipment. Resources programmed primarily for evaluation might better be spent in failure follow up and corrective action—a positive investment in reliability growth.

Department of Defense programs range from spacecraft that must operate untended for years, to one of a kind radar systems manned 24 hours a day; from missiles that have to work on command after years of storage to redundant communications equipment readily repaired with replaceable modules.

Practices appropriate to the more demanding applications tend to spread across the board, resulting in overkill and unnecessary cost. For example, high reliability electronic parts are obviously required for the unmanned spacecraft. Since the basic chips, and in most cases the packaging and assembly, are identical, the difference between high reliability and commercial parts these days lies primarily

in the screening and burn-in done to eliminate the imperfect devices that slip through the manufacturing process. Burn-in can reduce the already low commercial failure rate by a factor of ten or so, but increases the price by an even larger factor. The cost of high reliability parts should be compared to other ways of achieving satisfactory operational performance. For example, an attended, ground based radar could be assembled with commercial parts. The system, in effect, would do its own screening in the operational environment during the initial months of operation. Maintenance is required in either case, and the slightly higher cost of replacing one or two per cent of the devices in the system during the burn-in phase (probably with high reliability equivalents from Defense Supply Agency stores) would be more than offset by the lower acquisition cost. Incidentally, the increased failure rate might even provide the better training experience for a maintenance crew.

In the absence of concentrated management attention, opportunities for effective implementation of requirements can be inhibited by the conservatism inherent in an organization as large and structured as DOD. Military Specifications and Standards are a case in point. In a recent study* it was found that these documents, long a target for criticism, generally contain much more flexibility than appears to be used in practice. Industry was as guilty of over interpretation as Government was of over enforcement. Greater payoff can be expected from changing the method of application of specifications and standards than from improvement in the substantive content. The Government must recognize the inherently arbitrary nature of standardization, and establish a climate where the applicability of specific provisions can be challenged both by tailoring specifications to the particular needs of a given program and by granting cost effective waivers.

Since the existing procurement environment is basically conservative and encourages cautious conformance rather than forceful ingenuity, the Government Program Manager and the organization that supports him must be educated and motivated to realize that strict, parochial application of specifications and standards is neither required nor desired.

In effect, this recommendation to emphasize content, not form, is a natural extension of design-to-price principles to levels of detail not normally challenged.

UNCERTAINTY

The cocoon of formality that encases the development process from requirements, through proposal and negotiation to contract award often hides or deliberately subverts the basic uncertainties of maturing new equipment. Every development program contains uncertainty, since at least part of the equipment will see the light of day for the first time. A new design can not be brought to fruition without encountering some problems along the way. The amount of trouble is a function of the difficulty of design, but some unforeseen problems are inevitable even in the simplest of products. People are fallible, nature is a harsh task mistress, and no one organization can amass the talent (or afford to concentrate it in a single area), required to do things perfectly. Good R&D management is the art of controlling uncertainty with acceptable precision.

The obvious response to uncertainty is contingency, the elbow room in performance, schedule and cost required to cope with the unexpected while maintaining overall program commitments. Although, as noted, design-to-price has introduced a long overdue recognition of the flexibility required to balance performance and production cost; development schedules and funding remain problem areas.

Programs too often are squeezed into an arbitrary time frame, constrained by a required initial operation capability (IOC) date at one end, and a contract go-ahead on the other.

Initial planning often tends to be realistic, with adequate blocks of time for development, test, production and deployment. But

*Defense Science Board, "Report of the Task Force on Specifications and Standards," 15 Jan 77.

when the in-house Government decision process stretches out, there is reluctance to change the IOC date. Pressure is put on contractors to shorten the cycle, or, to be more accurate, to say that they can shorten the cycle. Often the net effect is counter productive. Production lead times are hard to change. Therefore, development and test tend to be squeezed. Engineering release is advanced, shortening the design and breadboard effort, and test time is reduced, lessening the ability to cope with failures encountered. *The program becomes success oriented at the sacrifice of the essential ingredients of success, i.e., adequate design, test and rework time. Program slippage and cost overrun become almost inevitable.*

An obvious solution is realistic scheduling with contingency time in the plan. But realism before the fact is in the eye of the beholder. Program Managers who have not grown up in research and development have little experience on which to base such judgments; and even the experienced Program Managers occasionally become cynical or succumb to the presumed pressures of the system.

The funding situation can be equally difficult. Any monies identified as contingency funds in a contractor's proposal are usually removed in negotiation, without compensating provision made by the Government.

Identified contingency provisions, based on the degree of difficulty of a program, could be a major step in schedule and cost overrun reduction. Whether the funds are retained by the Government or negotiated into contracts, and how such resources might be pooled (statistically) among programs, are subsidiary issues capable of a variety of solutions.

PRODUCT FOLLOW THROUGH

A qualification test program or Operational Test and Evaluation cannot be comprehensive enough to uncover all possible problems that may arise when complex new equipment is put into operational use. Prompt attention to such problems can be a major factor in achieving and even bettering reliability and maintainability goals.

In the commercial sector, the developer is usually responsible for installation and maintenance of his equipment on the customer's premises. To satisfy a customer the maintenance must be timely and effective. Good commercial organizations use the maintenance program to monitor the experienced mean-time-between-failure and the mean-time-to-repair of the fielded hardware. Anomalies can be quickly identified, and corrective action taken. Redesign, improved training or revised manuals can be expected to upgrade performance during the early years of product life.

The DOD procurement practices too often preclude the developer from following his product into the field. Maintenance is performed by uniform personnel supported by depots. Record keeping is difficult. Feedback to the developer is inadequate or nonexistent.

Much more can and should be done to keep the developer in the loop during the early years of product life. This organization will have both the interest and the expertise to solve the problems that arise. Based on experience with commercial operations, such involvement could be a major factor in eliminating unsatisfactory products from DOD inventories.

PERSONNEL AND ORGANIZATION

Research and development management is a skill that must be learned as any other skill is learned, through practice tempered by performance. Research and development management is a career of fundamental importance to the Services—a career equivalent to that of line command although demanding different, and specialized, training.

Despite the apparent precision of management systems that provide data and procedures to permit anyone with the right credentials to function in a given slot, in the real world it is the judgment and competence of the individuals involved that determine how well a program is run.

In a field as strewn with potential pitfalls as Defense Procurement, that involves a broad spectrum of technology (contractual requirements and organizational complexity), judgment can be gained only by experience. Individuals can be seasoned by serving at several levels of responsibility, learning from both the successes and failures found along the way.

Perhaps the best initial experience for a future Program Manager is to work on a program from inception to production, or development through deployment. It is the only way to learn, first hand,

- the changes that take place as system concepts are translated into designs,
- the lead times required to fabricate hardware,
- the nature of problems encountered in test,
- the problems that could have been anticipated and those that came as a surprise,
- the problems of production start up . . . on and on.

A Program Manager who has been through the mill knows when a schedule is realistic, can sense how much contingency is justified, and has a feel for the right ballpark on cost. Of even more importance, he can have the confidence and stature to do what is right for his program, to innovate in the interest of economy, and withstand pressures from outside sources that attempt to impose unreasonable requirements.

You learn from the problems, from the designs that do not meet specifications, from the missile that aborts, from the gun that hangs fire, from overruns and schedule slips, and from contractor promises vs observed performance.

There is no one correct way to run a program. Ultimately, the program must reflect the personality and competence of the Program Manager. He needs to be given some latitude to do things his way, especially when his track record is proven.

Acquisition management must be recognized as a career path in all the Services to assure the availability of experienced personnel to meet DOD needs.

In addition to experience, a Program Manager requires effective support to do an acceptable or superior job. A competent organization and appropriate delegation of authority are required, buttressed by effective management support.

The Program Office is the interface between government and industry, the major check and balance on contractor performance. The Program Office job is not just routine evaluation of cost and schedule progress.

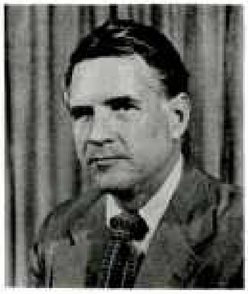
Far more important is the technical assessment of the contractor's approach and progress. The government experience may be broader than that of any individual contractor. Technical interchange between government and contractor is essential throughout the life of a development program.

To conduct a development program effectively the government technical people who support the Program Manager must be motivated not just toward technical excellence, but toward a balanced view of performance, cost and schedule. Few programs can afford the "world's best" anything. Programs will be more than successful if they can approach a "most adequate" status across the board, where most adequate is defined as "a little more than enough, but not too much." When the technical support to a Program Manager comes from in-house laboratories, particularly those geographically and organizationally separated from the Program Office, proper motivation may be difficult. Yet the Program Manager is often a captive of the judgments exercised by his technical people who are almost always performance driven. This aspect of the defense acquisition culture is perhaps the most difficult to change. One possible solution is to emphasize that laboratory support assignments are delegations of subsystem responsibility—not just for the areas of technical discipline involved, but for cost and schedule performance as well.

The Program Manager's job should be downward oriented, working with his organization, the contractors and the test and using

Commands. Reasonable management reporting is required. But too often, a typical Program Manager has the tremendous additional burden, especially on large programs, of being his own advocate, over and over, defending against reprogramming, preparing for DSARCs and rehearsing for intermediate level of command presentations. He lives in an environment that is careless of his time, distracts him from his main job and is potentially frustrating.

The Program Manager's job is not easy. The requirements for advocacy for his program, both within and outside DOD can consume a large portion of his time, at the expense of attention to the main task of running the program. Much can be done to provide the Program Manager stronger support and strengthen his ability to be an effective decisionmaker for his program. □



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Zero-Base Budgeting and *Sunset Legislation*

by

Lt. Col. Paul B. Demitriades, USAF Reserve

Zero-base budgeting (ZBB), an innovative budget technique, was developed in 1968 by Peter A. Pyhrr, at Texas Instruments, Inc. In 1971, Jimmy Carter, then Governor of Georgia, with Mr. Pyhrr as an advisor, introduced the zero-base budget concept for preparation of the state's fiscal year 1973 budget.

Mr. Phyrr's book, *Zero-Base Budgeting: A Practical Management Tool for Evaluating Expenses,*[1] is the first manual on budgets and planning, according to the *Washington Post*, to have caused a run on Washington, DC bookstores. The current popularity of this manual can be traced to President Carter's campaign promise that "Immediately after my inauguration, I will require zero-base budgeting for all Federal Departments, Bureaus, and Boards by Executive Order."

WHAT IS ZERO-BASE BUDGETING (ZBB)?

Most Government budgets traditionally have been prepared by line-item on an incremental basis, and allocation decisions have been made on the basis of prior levels of expenditure. Thus the budget for any given year becomes a product of the previous year's budget. Consequently, programs become entrenched, resistant to measures of program effectiveness and rational decisionmaking.

In contrast to the traditional "numbers oriented" approach of incrementing the new on old line items, "decision-oriented" zero-base budgeting requires that each program or function–new or old–in an organization must be justified in its entirety each time a new budget is formulated. The method does not assume any increase over the established base of expenditures, hence "zero-base."

There are four basic steps to zero-base budgeting:

(1) Identify decision units;
(2) Develop program decision packages. This requires analyzing and describing each discrete activity, current as well as new, in one or more decision packages;
(3) Rank program decision packages, (this involves evaluating and assigning a priority to the packages, through cost-benefit analysis and/or subjective evaluation). The consequences/impact of any changes, either from the current or recommended budget levels, are also identified;
(4) Allocate the budget on the basis of information derived from steps 1 through 3.

To provide decisionmaking alternatives zero-base budgeting usually requires that the budget request be based on program decision

packages developed to support several levels of operation, as illustrated in Figure 1:*

Program Decision Packages

Minimum objective level	Current objective level	Improvement objective level
The level below which it is not realistic nor feasible to operate program	The level that that represents a continuance of the previous year's level	The level of increase for an ongoing program

Figure 1, Alternative Program Decision Packages

The zero-base budget process is a bottoms-up management approach to planning that requires the involvement of managers at all levels of organization. The process demands an analytical framework, is usually a revelation to all who participate, and results in an improved quality of subsequent management judgments.** Although most applications of zero-base budgeting emphasize cost reduction, the process also provides an increased capability to respond quickly to growth situations, since all activities have been preplanned and given a priority. Figure 2 illustrates an example of format and content of a typical program decision package.[2]

- Purpose/Objective
- Description of action
- Cost and benefits
- Workload and performance measures
- Alternative means of accomplishing objectives

Figure 2, Program Decision Package

*For a discussion of the program decision package format, see "State of Georgia, Zero-Base Budget Procedures and Instructions for Fiscal Year 1978 Budget Development," Office of Planning & Budget, June 1976.

** For a review of ZBB results at a Canadian University and several utilities see: John F. MacFarlane, "Zero-Base Budgeting in Action," CA (Chartered Accountant), XXV(6): 20 (1976); and, Paul J. Stonich and William H. Steeves,"Zero-Base Planning and Budgeting for Utilities," *Public Utilities Fortnightly*, 97(9): 53 (1976).

ZERO-BASE BUDGETING AND PERFORMANCE EVALUATION

Zero-base budgeting assumes an ability to express clearly the goals and objectives of each decision unit being budgeted, as well as the goals and objectives of the entire organization. Regular zero-base review of Federal programs would require effective performance evaluation of program success or failure, a task of some magnitude. The Federal government is now spending at least $200 million a year for program evaluation according to the US General Accounting Office (GAO).[3] The US General Accounting Office and the Office of Management and Budget (OMB) have developed program evaluation guidelines to assist Federal departments and agencies.[4,5]

Guidelines have emphasized development of appropriate evaluation criteria as a component of agency legislative proposals and as an integral part of the implementation plan for new programs. In 1975 OMB developed, in draft form, several program evaluation guidelines selectively illustrated below:[6]

It is apparent the Federal Government faces a difficult task in determining objectives and carrying out evaluations required to implement ZBB. Mr. Charles H. Wilson, a US Congressman from California, recently summarized some general concerns on ZBB and program evaluation:

> "In summary, it should be clear now that ZBB, cannot simply be imposed on the entire Federal Government. Programs, program goals, objective, and evaluation techniques vary too widely. A system and methodology so flexible that it could be adapted to all programs would be meaningless. . . . any system rigourous enough to be successful in some cases would certainly not be appropriate in others.
>
> The management tool of zero-base budgeting can provide information on alternatives. But no budgeting system can make the ultimate decisions on priorities and the allocation of resources: Evaluation is still more art than science and is not a panacea. The rational process by itself cannot bear responsibility for criterion, continuation, or discontinuation of governmental programs. The

GUIDELINES	CONSIDERATIONS
1. Is the evaluation system an integral part and contributory part of the agency's decisionmaking processes?	• Formal connection between evaluation system and budget formulation and justification process. • Direct relationship between evaluation system and other management processes linking evaluation results with timetable for accomplishing objectives. • Early consideration of evaluation requirements during program design. • Does system maximize use of existing factual data?
2. Is there evidence of adequate attention to the administration of evaluation activities?	• Are agency evaluation units technically proficient to to perform evaluation? • Are individual evaluation projects planned and justified in the context of related and alternate projects? • Do evaluation-related data collection plans avoid unnecessary paperwork and protect privacy of individuals/organizations? • Are evaluation findings disseminated?
3. Is there a central focal point for evaluations within the department or agency?	• Is a senior policy official responsible for evaluation policy and criteria? • Is the focal point the most appropriate for responding to external requests for evaluation?

Figure 3, Program Evaluation Guidelines

real challenge is to policy-makers to use evaluation effectively, while recognizing uncertainties in information and limits of analysis."[7]

SUNSET LEGISLATION AND ZERO-BASE BUDGETING

The 93rd US Congress, in 1974, passed the Congressional Budget and Impoundment Control Act of 1974 (Public Law 93-344) which established a new congressional budget process, including House and Senate Budget Committees, a Congressional Budget Office (CBO), and a revised Federal Government Fiscal Year, beginning October 1, and effective October 1, 1976. The 1974 budget reform act is causing Congress, for the first time, to examine spending priorities with predetermined levels of revenue. Title VII of the Act authorizes Congressional Committees to conduct program testing or analysis of agency activities. Title VII also greatly expanded the General Accounting Office's program evaluation authority.

In 1976, Senator Edmund S. Muskie, (D.), Maine, Chairman of the Senate Budget Committee, and Senator William V. Roth, Jr., (R.), Delaware, introduced in the 94th Congress, Senate Bill S. 2925, the "Government Economy and Spending Reform Act of 1976," that proposed a procedure for zero-base review and evaluation of Government programs and activities every 5 years. Senate Bill S. 2925 became known as the "Sunset Bill" because the sun could set on programs with unfavorable reviews, and all programs would have finite expiration dates in the enabling legislation.

Congressional leaders consider Sunset review as logical extensions of the new congressional budget process. Where the current budget process set spending priorities, Sunset reviews provide a method of determining whether Federal Programs are meeting these priorities.

The Muskie-Roth Bill would have terminated the authorization provisions for nearly all Federal Programs every 5 years. Exempt from the "Sunset provision" would be social security, other pension programs, medicare and interest payments on the na-

tional debt. Tax expenditure provisions (generally defined in the Internal Revenue Code of 1954) that allow a special exclusion, exemption, or deduction for determining tax liability were also included within the provisions of the bill, since they are considered to be revenue losses to the US Treasury.

Programs could not be continued beyond their expiration dates unless Congress and the Administration conducted a program zero-base review, 1 year prior to scheduled expiration date.

Many members of Congress, during Senate and House hearings on the proposed Sunset legislation, expressed concern over the inflexibility of the 5-year reauthorization period, and the rigidity of the proposed procedures.[8] Executive branch concerns focus on the increased ZBB paperwork burden and the extended and involved decisionmaking period required. Senate Bill S. 2925 and a companion House Bill (H.R. 11734) died with the end of the 94th Congress. Senator Muskie and a bipartisan group of 41 US senators, introduced on January 10, 1977, Senate Bill S. 2, entitled "The Sunset Act of 1977." Senate Bill S. 2 "requires authorizations of new budget authority for Government programs at least every 5 years, to provide for review of Government programs every 5 years, and for other purposes."[9]

Programs performing similar functions would be grouped into program decision packages, and terminate in the same year, so that Congress could review them as a package. The first package to expire would require reauthorization after September 30, 1979. National Defense programs, functional category 050, would be included in the first review period. Another set of program decision packages would follow at the end of each fiscal year, ending in Fiscal Year 1983. Each subsequent review date applicable to a program is the date 5 years following the preceding review date. The 5-year process is intended to balance Congressional Committee workload.

Sunset review would determine if the merits of the programs justify continuation rather than termination, or continuation at a *level less than, equal to, or greater than the existing level.* Senate Bill S. 2 differs substantially from Senate Bill S. 2925, as a result of Hearings, and an apparent philosophical change that emphasizes Sunset (including tax expenditures) rather than ZBB provisions.

To alleviate Congressional concerns, a US House of Representatives Appropriations Subcommittee devised a limited test of ZBB. The experiment began in late 1976 when the Consumer Product Safety Commission and the National Aeronautics and Space Administration (NASA) were directed to prepare their Fiscal Year 1978 (October 1, 1977 through September 30, 1978) budget materials using both the usual technique and ZBB procedures. The two agencies were selected by the Subcommittee because technical activities of these agencies could be more easily measured than some other agencies in the Subcommittee's jurisdiction. "While it is too early to draw comprehensive conclusions, the project has generated the feeling among those involved that it would be extremely difficult to institute zero-base budgeting across the entire Government and receive great results the first year."[10] The Subcommittee plans to have the General Accounting Office and the Congressional Budget Office evaluate the experiment.

As shown in Figure 4, the proposed Sunset Act of 1977 timetable may add significantly to Congressional information demands from the Department of Defense. The approach builds on the fixed budget timetable adopted in the Congressional Budget and Impoundment Control Act of 1974.[11]

As presently conceived in the Federal government, ZBB is primarily a managerial instrument of executive budgeting, while Sunset, especially as defined in Senate Bill S. 2, is linked to law-making functions and becomes a legislative device.* Zero-base budgeting and

*For a comparison of the features and uses of ZBB/Sunset by the Executive and Legislative branches of government, see the testimony of Allen Schick, Congressional Research Service, in "Zero-Base Budget Legislation," Reference 8, p. 51.

ON OR BEFORE	ACTION
September 1, 1977	House and Senate Budget Committees report to Congress on relationship between tax expenditure provisions and related programs.
January 1, 1978	General Accounting Office/Congressional Budget Office with OMB submit to Congress analysis of all programs including enabling legislation. Joint Committee on taxation identifies/ recommends tax expenditure provision termination dates.
March 1, 1978	House and Senate Budget and Appropriations Committees complete review of report.
October 1, 1978	General Accounting Office furnishes Congressional Committees results of prior audits for programs and tax expenditure provisions included in first annual Sunset review. Fiscal year begins.
May 15, 1979	Congressional Committees complete and submit reports on each program to the House or Senate.
September 30, 1979	Congress completes first annual program Sunset review.
September 30, 1980	Congress completes 2nd annual program Sunset review. Citizens' Commission on the Organization and Operation of Government final report to President/Congress.
September 30, 1981	Congress completes third annual program Sunset review.
September 30, 1982	Congress completes fourth annual program Sunset reviews.
September 30, 1983	Congress completes fifth annual program Sunset review. (Repeat cycle as required.)

Figure 4, Proposed Sunset Act Timetable

Source: Senate Bill S. 2, 95th Congress
1st Session

Sunset Legislation use different but complementary procedures, and share a common objective: to compel periodic review of every Federal program to determine whether it should be continued.

ZERO-BASE BUDGETING AND THE DOD PLANNING, PROGRAMMING, BUDGETING SYSTEM

The Office of Management and Budget issued to all agencies in early 1977 ZBB instructions* applicable to the preparation, analysis, and justification of fiscal year 1979 budget requests.[12] The required/optional decision package set is illustrated in Figure 5:

Proposed changes (supplementals, amendments, recissions) in current year amounts, and new programs or activities are to be proposed in separate decision packages.

Department of Defense compliance with the Office of Management and Budget ZBB requirements should be facilitated by the "Five Year Defense Program (FYDP)" which aggregates information at the program (Strategic Forces, e.g.) and package (Minuteman Squadrons, e.g.) levels; and information required by the Planning, Programming, Budgeting System structure and related DOD policy documents.[13,14,15] As ZBB implementation proceeds, DOD resource management systems may require modification to respond to a revised budgetary process.

As recently pointed out by the Assistant Secretary of Defense–Comptroller, ZBB differs in three major respects from past DOD

*Directed to the Heads of Executive Departments and Establishments.

Required	Current Level	Represents continuance of previous year's level
	Minimum Level	The level below which it is not feasible to continue.
Optional	A level or levels between the minimum and current levels	
	Any additional increments desired above the current level.	

Figure 5, Decision Package Set

PPBS practices: "First, there will be many more decision packages than in the past. Military components will submit several (not one) decision packages for each (decision) unit, and the options to be considered also will increase in number. Second, the package for the lowest resource level must include an explicit zero-base justification. And, third, the package must be ranked."[16]

PRESIDENT CARTER'S VIEWS

In the January 1977 issue of *Nation's Business,*[17] President Carter described why he will use zero-base budgeting during his administration.

"From my experience in government, as well as the experience of corporations in the business world, a number of clear-cut benefits from an effective zero-base budgeting effort can be cited. These benefits include:

- **Focusing the management process on analysis and decisionmaking, rather than simply on numbers;**
- **Combining planning, budgeting, and operational decisionmaking into one process;**
- **Forcing managers to evaluate in detail the cost-effectiveness of their operations;**
- **Providing a system to trade-off between long-term and short-term needs during the budgeting period, as well as a follow-up tool on cost and performance during the year;**
- **Allowing for quick budget adjustments or resource shifts during the year, if necessary, when revenue falls short;**
- **Identifying similar functions among different departments for comparison and evaluation;**
- **And, most important to me, broadly expanding management participation and training in the planning, budgeting, and decisionmaking process."**

IMPLICATIONS FOR THE FUTURE

The President has stated his commitment to ZBB, reorganizing government to improve efficiency, and providing increased citizen access to government. Since Watergate, government has lost some credibility, and there is growing concern about continued growth of public sector spending programs. The new budgetary process adopted by the Congress in 1974 is one reflection of these concerns, and there is considerable support for budget reform, reflected by ZBB and Sunset Legislation. Although the immediate imposition of ZBB and Sunset reviews throughout the Federal Government may be unlikely, current Legislative and Executive Branch budget reform efforts presage a coming major change in the US Government's budget process. □

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The Army Budget and Combat Capability

by

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The US Army Concepts Analysis Agency is developing a quantitative means by which to assess changes in the Army's combat capabilities resulting from real or expected changes in Army budgets. This effort incorporates both an econometric model of the Army and a theater combat simulation model within an overall methodology framework. The linking of the fiscal model with a combat effectiveness model is a unique feature of this project.

INTRODUCTION

The Army's budget and the Army's combat capability must, logically, be related to one another. An Army program is developed to counter a threat, improve readiness and attain a myriad of other objectives. Fiscal arrangements are then designed to support the program. It follows that if the budget is changed the capability will change. This interaction was a concern of the then Under Secretary of the Army, Norman Augustine, who, in November 1975, requested that the US Army Concepts Analysis Agency (CAA) define an approach to link the budget to a measure of combat capability. The project was accomplished in slightly over 3 months time and is referred to as the 100-Day Study.

The 100-Day Study provided a methodology for ascribing effectiveness to a budget. It showed that there was a way to measure combat capability changes resulting from budget changes. It also indicated that effectiveness per budgeted dollar factors could be determined which would be useful in considering budget alternatives. The methodology proposed in the 100-Day Study was favorably received but the concept required refinement and testing before it could be made available to the Army Staff. The Army Dollar Resource Allocation-Phase II (ADRA II) Study evolved from that effort. The ADRA II Study results in an analytical mechanism for use by the Army Staff in formulating and supporting Army plans, programs and budgets. This article presents the basic ADRA methodology and proposes potential applications.

MAJOR ASSUMPTIONS

The following major assumptions were applied to make the problem tractable:

- The Army can be represented as an economic system having producing and consuming sectors.

- Input-output analysis, an econometric modeling technique, is appropriate for use in describing the interrelationships within the Army.

METHODOLOGY

The Army is viewed as an economic system consisting of producing and consuming sectors. This Army economy is modeled using the techniques of input-output theory.[1,2,3*] The input-out model thus derived is utilized to compute how the dollars in the Army output sectors (e.g., the division forces) change when the input (budget) changes. Also the theory can be applied to compute the budget required to assure a desired level of dollars in the output sectors.

In a separate analysis a value for an effectiveness measure was established. The measure used is the Weighted Unit Value (WUV) score which is a value based on the number of weapons in a force, and the firepower, maneuverability, survivability and other characteristics of these weapons. The WUV scores, in Army Dollar Resource Allocation, are computed for the force projected in the Army Program Objective Memorandum (POM) and a separate value is computed for each year of the POM period. This effectiveness measure is used in the computation of effectiveness per dollar factors and as a primary input to a dynamic, macro-level combat simulation model; the model provides an assessment of the Army's combat capability in a North Atlantic Treaty Organization, Central Europe, mid-intensity war.

The methodology is synopsized in Figure 1. Starting with data contained in the Five Year Defense Program (FYDP) and the POM, a base case fiscal arrangement and force effectiveness measure (WUV score) are combined to produce effectiveness per dollar factors for each Army sector and appropriation. All dollar figures in the Five Year Defense Program are converted to constant dollars to negate the influence of inflation. Also a combat simulation is performed to estimate the war fighting performance of the base case force. The process just described constitutes calibrating the Army Dollar Resource Allocation model to the base case. The results of this calibration are required as a foundation from which to assess the impact of changes in Army capability resulting from changes in the budget. To examine a budget change, factors are applied to compute the dollar changes at the output sector. Those output changes, together with the previously computed effectiveness per dollar factors allow the overall change in effectiveness (WUV) to be computed. To complete the procedure, the revised WUV score resulting from the dollar change is input to the combat simulation model and the resulting combat capability is compared to that of the base case.

*See references for discussions of input-output theory.

THE ADRA PROCESS

The description contained in the preceding paragraph was a general review of the ADRA methodology. The Army Dollar Resource Allocation information process is shown in Figure 2. The Five-Year Defense Program contains the dollars associated with each Army program element. A set of sector composition rules is applied to compute the dollars contained in each Army economic sector. That money is distributed throughout the Army economy by use of a set of fiscal allocation rules. Then a set of WUV allocation rules is applied to associate the effectivenss measure with a dollar value for each sector and appropriation. The material which follows provides greater detail regarding the Army sectors and their composition, the distribution of dollars, and the computation of the effectiveness per dollar values.

Army Sectors

The sectors of the Army economy are extensions of the ten Five-Year Defense Programs; see Table 1. For instance, Program 3 (Intelligence and Communication) was considered as constituting two sectors: the Intelligence sector, and the Communications sector. It was reasoned that for the concept of economic sectors to gain acceptance and provide maximum utility, the sectors should be terms familiar to Army financial planners and managers—the Five-Year Defense Programs met that criterion. The only exception was the Base Operations sector. Base Operations is not a Five Year Defense Program but it is a highly visible and integral facet of the

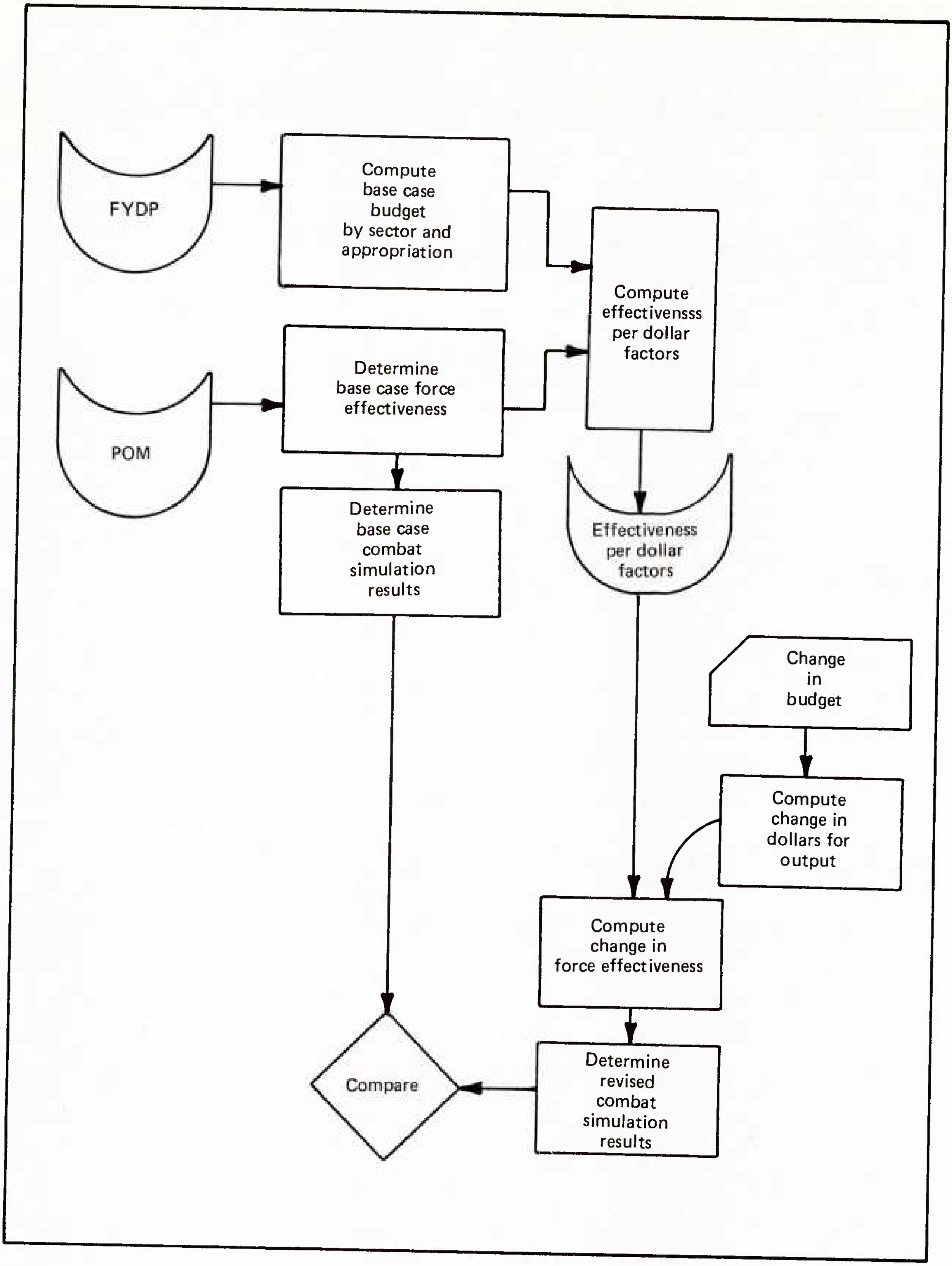

Figure 1. Synopsis of Army Dollar Resource Allocation Methodology.

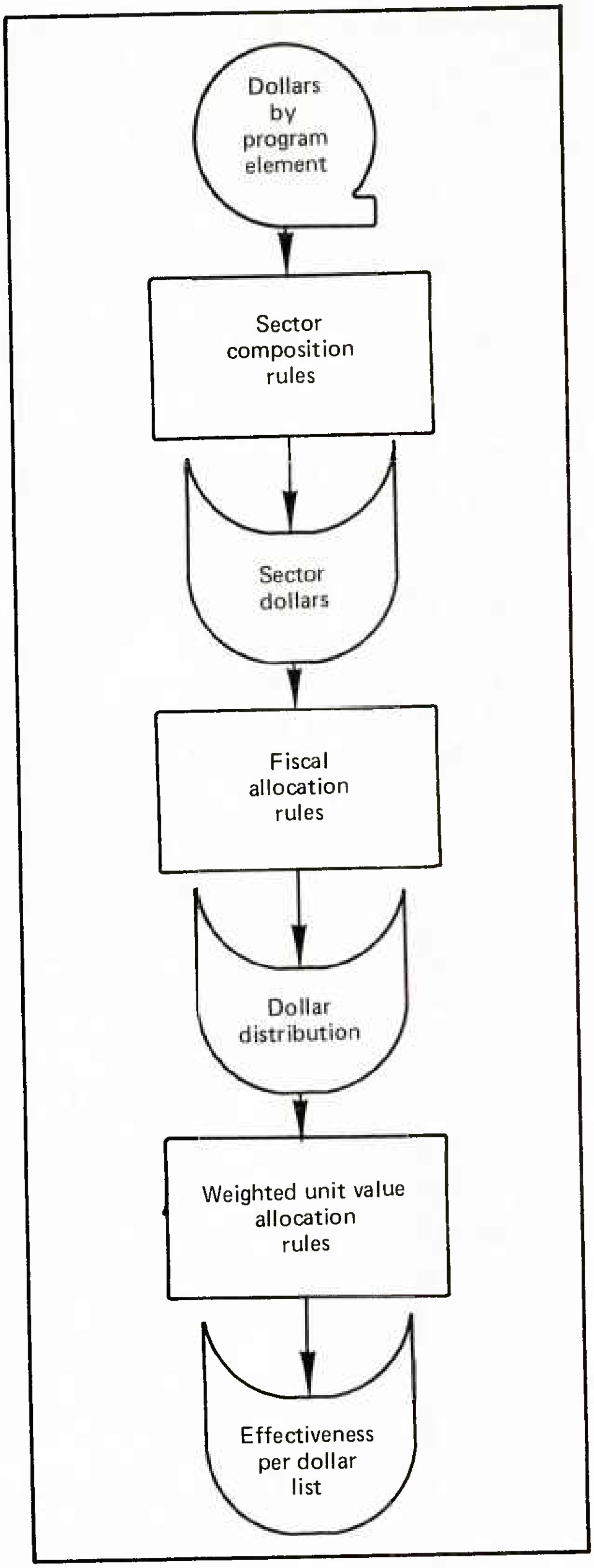

Figure 2. Army Dollar Resource Allocation Information Process.

Table 1. Sectors of the Army Economy

Support Sectors	Operational Sectors
Base Operations	Strategic Forces
Intelligence	National Guard
Communications	Army Reserve
Airlift and Sealift	General Purpose Forces (Division Forces)
Research	General Purpose Forces (Other)
Development	Support of Other Nations (Operational)
Supply	
Maintenance	
Training	
Medical	
Other (Program 8)	
Administration	
Support of Other Nations (MAAG/Mission)	

Army, receiving considerable attention and scrutiny from the Office of the Secretary of Defense and the Congress; therefore it was established as a separate sector.

Sector Composition

After having established the sectors of the Army economy, it was necessary to determine the individual sector composition or construction in order to associate a dollar value with each sector. Again, the Five Year Defense Program was used to aid this process. There are approximately 700 program elements in the Army's portion of the Five Year Defense Program and each program element is defined in DOD Handbook 7045.7-H.[4] A Department of the Army working group reviewed each program element and assigned it to one of the 19 Army sectors. Since the Five Year Defense Program contains fiscal data by appropriation for each program element, summing the dollars associated with the program elements in a sector provides the budget for each sector, by appropriation.

Dollar Distribution

The next step in the methodology requires distributing the budget for each sector throughout the Army. To distribute the

budget, each sector is considered a producer—its budget allows the sector to produce goods or services available to the Army economy; each sector is also considered a consumer—it creates demands for the goods or services produced by the sectors. A set of dollar allocation rules is used to distribute the dollars from the producers to the consumers.

The process of distributing the dollars throughout the Army economy is illustrated in Figure 3. Consider a simplified Army consisting of 4 sectors one of which is the Training sector. Further assume that the Training sector is comprised of two program elements: recruit training and specialized training. For any appropriation, the sum of the budgets for the two program elements constitutes the budget for the Training sector. That sector budget is spent to train personnel in each sector (including the training sector since training personnel must also be trained). If it is assumed that the Training sector allocates its resources according to the number of people in each sector, then the training budget can be distributed *from* the Training sector *to* all sectors in proportion to the personnel in each sector. Each producing sector's budget can be distributed by a rationale that reflects the goods or services provided by the producer's dollars.

The dollar distribution procedure is repeated for each appropriation using separate allocation rules to reflect the different goods or services provided by each appropriation (e.g., the Aircraft Procurement appropriation can be used only to buy aircraft related parts and equipment—it may not be used to pay salaries; Military Personnel, Army (MPA) money is used only for active duty military—it cannot be used to buy hardware). The result of distributing the entire budget (all sectors, all appropriations) is portrayed in Figure 4.

Dollars for Output. If the rightmost column of Figure 4 represents the output sector of the Army, then the shaded area contains that portion of the budget demanded (or consumed) by the output sector. That is, it contains the dollars from each sector (by appropriation) allocated in support of the output sector.

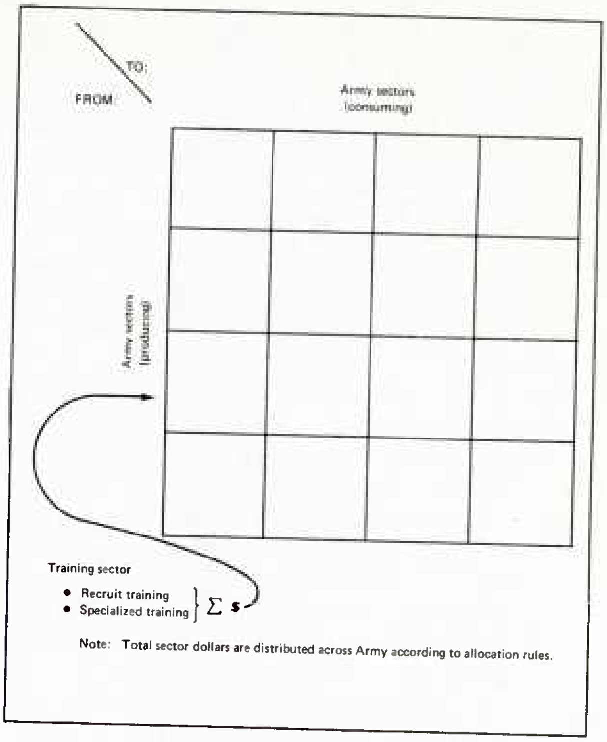

Figure 3. Dollar Distribution

Effectiveness per Dollar. Applying the methodology just described yields the dollars, by sector and appropriation, that support the division forces. As indicated previously, the effectiveness measure of the force is expressed in terms of WUV. The WUV score is linked to the sectors and appropriations

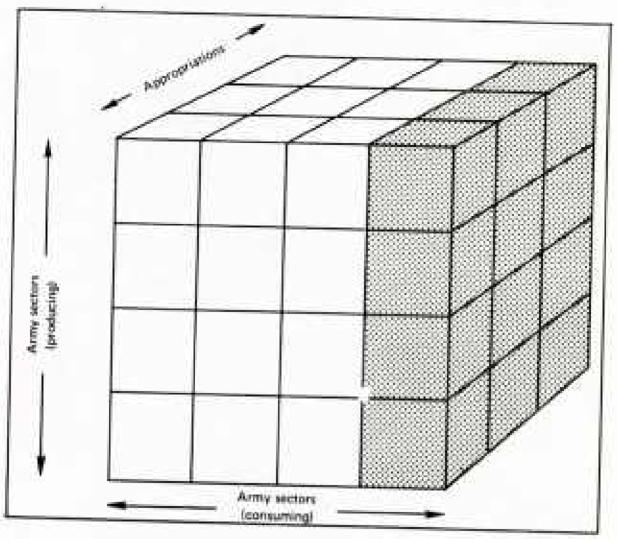

Figure 4. Total Budget Distribution

utilizing a methodology that relates WUV to the dollar distribution. First, the WUV associated with each sector is computed. Then each sector's WUV value is distributed among the appropriations that comprise the sector. Dividing the resultant WUV by the appropriation dollars yields a WUV per dollar value for each sector-appropriation pair. Arraying these WUV per dollar values from highest to lowest produces an ordered list that can be used to assess the impact of budget change since the product of the dollar change to a sector-appropriation times its WUV per dollar factor provides the change in WUV. The list can also reveal areas of high or low dollar leverage in terms of combat capability. Sector-appropriation pairs with high WUV per dollar factors would be prime candidates for increased funding while reductions would be preferable in those sector-appropriation pairs with low factors. The computation of the ordered list is the final step in establishing a base case.

POTENTIAL USES

The ADRA methodology may be applied throughout the program/budget cycle. Uses which appear to offer greatest potential benefit are given here.

Identification of Leverage Points

A budget and an associated force effectiveness (WUV) score are selected to establish a base case. An example could be the budget request which the Department of the Army submits to the Office of the Secretary of Defense each October. As previously indicated the budget and the WUV score computed for the Army are combined to produce a WUV per dollar list which is arranged in descending numerical order. The list can be used directly to identify areas of high or low leverage in terms of combat capability (i.e., determine prime candidates for dollar increments or decrements to have the most favorable impact on combat effectiveness). The list is necessary to assess the impact of dollar changes.

Assessment of Directed Change

Changes to the base case budget may be directed by the Army Staff or higher authority. Review of the change rationale can reveal the sectors and appropriations affected. For example, if the Operations and Maintenance, Army (OMA) budget for the Supply sector is to be reduced by a given amount, then that dollar reduction multiplied by the WUV per dollar factor for OMA–Supply yields the resultant change in WUV. A repeat of this operation for each affected appropriation-sector pair provides the total change in WUV associated with specific changes in the budget. Then operating the combat simulation model with the revised WUV score allows the impact of the dollar change to be assessed in terms of combat capability.

Formulation of Alternatives

The ability to prepare alternatives to dollar changes directed by higher authority is inherent to the ADRA methodology. Such alternatives can be constructed to retain the highest possible combat capability in the face of pressures for dollar reduction. The amount of real or expected changes to the base case budget is the input required to prepare alternatives. The ADRA methodology generates alternatives based on the ordered list of WUV per dollar factors. If, for example, an alternative way to absorb a $100 million cut is desired, the lowest WUV per dollar appropriation-sector combinations would seem appropriate for consideration. By absorbing a cut starting with the elements at the bottom of the WUV per dollar list, an alternative can be generated that minimizes the detriment to Army combat capability (e.g., an alternative with the smallest reduction in WUV). If an increase in budget is contemplated, money could be added by appropriation-sector starting at the top of the WUV per dollar list to most favorably impact combat capability. Such alternatives would place additional money into the elements that would produce the highest WUV.

Application of Fences

When considering alternatives, whether increasing or decreasing the budget, fences (i.e., fixed dollar levels) can be applied at the sector, appropriation or combined sector-appropriation level. Thus, if an alternative

to a budget cut is being generated, the Army Dollar Resource Allocation system can be instructed to refrain, for example, from deleting any Military Personnel, Army (MPA) dollars, or to delete no more than $10 million from the OMB-Base Operations budget; the number of fences is unlimited within the Army Dollar Resource Allocation framework. The utility of this feature is that it allows the construction of alternatives that reflect realistic and desirable constraints within the Army program/budget structure.

SUMMARY

Based upon the analysis performed thus far in the Army Dollar Resource Allocation project, the following points have been observed:

- The employment of the ADRA methodology is feasible and potentially useful in the Army program and budget cycle. The impact of real or expected fiscal changes can be evaluated in terms of combat capability in a single year or over a series of years.

- Alternative programs or budgets can be generated and evaluated. The choices can reflect fences (fixed levels) or limits (floors, ceilings) on budget adjustments to preserve Army capabilities or options.

- Quantitative arguments can be developed to help defend the Army program and budgets from detrimental cuts; multiple choices can be prepared rapidly with the Army Dollar Resource Allocation operational system.

- Tests with data from past Program/Budget Decision cycles indicate that faced with dollar reductions, the more control the Army retains over how to absorb the cut, the less detrimental is the impact on combat capability. If the Army is permitted to select both the sectors and the appropriations being reduced, a higher effectiveness can result than when only the sectors can be designated by the Army.

The ADRA methodology is embodied in an automated data processing system that permits rapid turnaround to facilitate formulation and evaluation of alternative Army programs and budgets. The ADRA II study effort incorporates both an econometric model of the Army and a theater combat simulation model within an overall methodology framework. This linking of the fiscal model with a combat effectiveness model is a unique feature of the Army Dollar Resource Allocation effort allowing the impact of budget changes to be assessed quantitatively in terms of combat capability. Each of these constituent models address key parameters at aggregate or macro levels of activity: the input-output structure employed for the econometric model represents an aggregation of budget components of the Army; the combat simulation model aggregates military activity for a theater-wide campaign. Consequently, the interface of these models provides for macro analytic treatment of the linkage between Army budgets and combat effectiveness. Applications of the ADRA methodology can be targeted to levels of analysis consistent with those of the major component models.

WHAT NEXT?

The methodology described in this article is being programmed for operations on automated data processing equipment of the US Army Management Systems Support Agency in the Pentagon. This will provide the Army Staff a responsive in-house ability to use the Army Dollar Resource Allocation system. Over the next year, extensive operational testing will be accomplished to guage the adequacy of the system design and establish its usefulness in the Planning, Programming and Budgeting System. Application will be tested:

- In the Major Issue Cycle (Jun-Aug)
- In the Program/Budget Decision Cycle (Nov-Dec)
- In Program Formulation (Jan-Feb)

By April 1978 the Army will have completed developing and testing the ADRA methodology. □

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Establishing the FAE II

by

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and

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As greater emphasis is given joint and triservice national defense programs, service cooperation becomes increasingly important. In this article the FAE II Program, based on fuel-air explosive technology, is reviewed. The difficulties stated, both technical and procedural, are typical of those encountered in the beginning phases of any functioning joint service development program. The resolutions agreed upon by the Navy-Air Force team to facilitate working relations are presented and insights are provided for those who become engaged in future joint service development programs.

FUEL-AIR EXPLOSIVE TECHNOLOGY

A fuel-air explosive (FAE) weapon is a blast-producing device that has minimum fragmentation and incendiary effects. The results of a fuel-air explosive detonation can be characterized by a homogeneous effects region around the functioning point and a short, predictable cutoff range from the region of effectiveness to a region of complete safety. The detonation of a fragmentation munition, by contrast, *gradually* decays in effectiveness from the region near the warhead. Hence there is a probability of damage, although low, at great distances from the impact point. The fuel-air explosive attribute of limited cutoff range is viewed favorably by friendly ground forces as ordnance, on occasion, must be employed close to friendly positions. Too, the limited cutoff range is important when targets must be engaged that are close to nontargets (such as churches or schools) or when targets are near to enemy equipment and facilities that could be used by capturing forces.

A fuel-air warhead differs from a conventional explosive-filled war head in that the oxidizer necessary for detonation can be obtained from the air. An FAE device carries only its fuel. Thus more energy can be obtained within the given volume or weight envelop of the weapon.

Both the Navy and the Air Force pursued research and technology efforts leading to the development of first-generation weapons. The CBU-55 used by the Air Force and the Navy, and by the Republic of Vietnam, was developed and produced by the Navy. The Air Force developed the BLU-76, that underwent examination in Vietnam (the BLU-76 was not

a production model). Both the CBU-55 and the BLU-76 required large parachutes to slow the weapons to the low velocity *then* necessary to obtain reliable function. Weapon designs of this first generation necessitated restriction of aircraft delivery envelop and made accurate delivery nearly impossible. Long times of fall, resulting from the slow velocity, allowed wind drift to deflect the weapon from its target.

THE FAE II PROGRAM

The FAE II was envisioned as a second generation fuel air explosive weapon designed to overcome delivery and accuracy limitations.

Both the Navy and Air Force conducted exploratory and advanced development efforts seeking solutions to the problem of high-velocity functioning of advanced FAE weapons. A number of formidable problems resulted from the requirement for weapon function at high and variable terminal velocities. Each service approached the problems differently and strong opinions were formed over the best method of achieving a functional weapon. Opinion also differed over the state of the art in FAE technology. The Air Force adopted a conservative approach and the Navy advocated prompt entry into engineering development. The process of resolving these differences played a dominant role in the FAE II Program and had a major impact on the working relations established between the services.

LEAD SERVICE DETERMINATION AND JSOR GENERATION

The Department of Defense has become increasingly involved with reducing proliferation of weapon systems while reducing waste associated with duplication of development efforts. Early in 1971 harmonization requirements were generated that established the framework for joint service programs.* The Air Munitions Requirements and Development (AMRAD) Committee was established under the Director of Defense Research and Engineering** to ensure coordination of requirements. By 1973 it was apparent that the FAE II development efforts of the Navy and Air Force were candidates for a joint program.

(Note: The FAE II was not a major program. The existing procedural framework*** for joint service projects had been written for major programs and called for charters, program offices at high organizational levels, memoranda of understanding, and many other items not consistent with organizations and budgets available for less-than-major projects. Little useful procedural guidance was available for setting up a FAE II joint service development program.)

The task then addressed was the selection of the lead service for the FAE II program. No firm prerequisites or requirements exist that must be satisfied by a service prior to its being selected the lead service. The guidelines imply that the service staffing the Requirements/Objectives (R/O) document through the system to the AMRAD Committee has the best opportunity to become lead service. In the case of the FAE II willingness by Navy headquarters to support the program counted heavily in the selection of Navy as the lead service.

The Joint Service Agreement on Harmonization of Service Requirements and Characteristics for Air Munitions states that a R/O should be prepared about 1 year before initiation of engineering development. The technical prerequisites for entering engineering development are not defined beyond the general statement that "feasibility must have been demonstrated." The objective of advanced development is to resolve unknowns and verify that the technical and economic bases for initiating engineering development

*Department of Defense Research and Engineering (DDR&E). Joint Service Agreement: "Harmonization of Service Qualitative Requirements and Characteristics for Air Munitions," (DDR&E memo dtd. 27 Jan 71).

**Joint Service Agreement on Harmonization of Service Requirements and Characteristics for Air Munitions signed by Secretary of Defense Packard, 30 Apr 71.

***Department of the Navy, NAVMAT Instr. 5000.10A, "Air Force, Army and Navy Agreement on the Management of Multi-Service Systems, Programs, and Projects," 4 Sep 73. (superseding NAVMAT Instr. 5000.10 dtd 25 Apr 68.)

of the weapon system are valid. Demonstration of feasibility during advanced development may be subject to various interpretations ranging from a convincing engineering analysis to a functioning prototype device. In general a brassboard and advanced prototyping effort is necessary to confirm that the technology is feasible and that the design concept has military value and utility. A judgment must be made as to whether the feasibility demonstration indicates acceptable risk in proceeding to the next phase of development. Whether a risk is acceptable or not is influenced by many factors difficult to quantify.

With the stated prerequisites as a guide, the Navy submitted the FAE II R/O document to the AMRAD Committee in March of 1973. The submittal was justified on the basis of work completed, leading to the belief that engineering development could be initiated within 1 year. This action was considered premature by the Air Force development group at Eglin Air Force Base. The Air Force position was based on the opinion that neither service would be able to demonstrate a functional prototype device prior to the engineering development proposed start date.

On 24 April 1973, the AMRAD Committee transmitted the Navy R/O document to the other services requesting comments and recommendations.* The R/O document contained a preliminary operational requirement that called for a single 1,000-pound class weapon. On 1 August 1973, the AMRAD Committee concluded review of the service comments and promulgated a Determination and Findings** that:

- Designated the development of a joint requirement.
- Required the generation of a joint service operational requirement (JSOR) within 60 working days.
- Made the Navy responsible for preparation and coordination of the JSOR.
- Authorized both service-advanced development efforts to continue through fiscal year 1974.

The requirement to complete the JSOR within 60 working days proved to be too short a time for accomplishment. Although the Service Secretary was the action addressee, the performance of work occurs much lower in the chain of command and must be officially delegated. Typically, the necessary time for delegation was not given consideration. In this case, the action message was received by the Naval Weapons Center (NWC) 31 days after the AMRAD Committee had set a deadline for the finally coordinated JSOR. Almost half the available time was taken to get the action; and more time was required to implement the process. Almost no time was left to do the work.

The mechanism used for joint service operational requirement coordination was the Working Party for Fuel Air Explosives of the Joint Technical Coordinating Group for Air-Launched Non-Nuclear Ordnance (JTCG/ALNNO). Use of this group offered a previously established, informal chain of command prior to final submission of the program to the Chief of Naval Operations (CNO) and to the Air Force Staff. A final draft was generated and submitted to the Naval Air Systems Command (NAVAIR) on 27 September 1973. The NAVAIR endorsed the draft and submitted it to CNO on 19 October. Ten days later, the Chief of Naval Operations approved the draft and submitted it to Air Staff, Department of the Army, and Marine Corps Headquarters, along with the request that a reply be provided by 2 November 1973. The final joint service operational requirement was approved and submitted to the AMRAD Committee on 26 November.

This schedule was possible only because action was based on verbal authorization long before formal authorization was provided. In this case, all parties were cooperative. In other instances, progress has been stopped because a task could not be assumed until after it had been given its official sanction.

*Air Munitions Requirements and Development ltr dated 24 April 73.

**Air Munitions Requirements and Development ltr dated 1 Aug 73.

As the draft joint service operational requirement went through the review process, several significant changes were made. The changes included:

- The one 1,000-pound class weapon was changed to specify one 500-pound and one 2,000-pound class weapon.

- Addition of a requirement for a foliage-discriminating fuze.

- Addition of a desired, but not required, capability for supersonic delivery and a 150-knot arming speed.

- Addition of a requirement for an unspecified guidance compatibility in the 2,000-pound weapon.

The results of these changes were significant. The development of two versions of weapon instead of one would significantly increase the development cost. The foliage discrimination fuze requirement imposed a potentially significant fuze cost increase. The desired supersonic release capability and the 150-knot minimum arming speed represented a long-standing difference in opinion between the services that has yet to be resolved.

The AMRAD Committee, on 3 January 1974, promulgated a Standardization/Recommendation that:

- Approved the JSOR.

- Reaffirmed a joint requirement (joint development and procurement implied).

- Designated the Navy as lead service with the Air Force as participant and the Army as monitor.

- Established that joint test and evaluation be conducted under the monitorship of ODDR&E.

- Established a joint management structure for positive resolution of critical technical issues.

- Required a Joint Development Plan (JDP) in 90 working days.

CREATION OF A JOINT DEVELOPMENT PLAN

On 3 January 1974, the Director of Defense Research and Engineering approved the FAE II joint service project and requested the Secretary of the Navy to prepare a Joint Development Plan (JDP) in 90 working days. The Naval Weapons Center received the action to prepare the JDP on 1 February. Assistance was requested immediately from the Armament Development and Test Center.

The Chairman of the JTCG/ALNNO (now designated Joint Technical Coordinating Group for Munitions Development, or JTCG/MD), on 1 February 1974, requested that the Joint Development Plan be written by the Working Party for FAE. The previous day, the Joint Logistics Commanders had directed* that joint service plans and programs be prepared by the JTCG organization. This requirement did not create a problem in that the key Air Force and Navy people in the FAE II project were members of the Joint Technical Coordination Group.

The Joint Development Plan was written and rewritten many times during the period from February through July 1974. Originally, the plan was to include only the small weapon. The later requirement to develop both weapons concurrently created a major perturbation, primarily from a costing viewpoint.

Only one joint service project, the Gator project, had previously been planned and approved under the current guidelines. The Gator plan was recommended as a guideline. The following sections of the plan were among those required:

Project Summary/Authorizations

Intelligence/Threat

Operations

Program Management

*Joint Logistic Commanders ltr to the Chief of Naval Operations, the Chief of Staff, Air Force, and the Chief of Staff, Army, dated 30 Jan 74.

Funding and Schedules

System Engineering

Test and Evaluation

Facilities

Logistics

Human Factors Engineering/Personnel

Training/Support

Security

Applicable MIL-STD/Specifications

Environmental Impact

A Joint Development Plan it appears, is usually viewed as a necessarily all-encompassing document. In this document, every conceivable factor has been considered, planned, debated, negotiated, and included. The result is a wordy document that is read in detail only by the negotiator/writer. The document is costly, bulky, and time-consuming to prepare. At this stage of a development program, it is realistic to include all pertinent factors, but with emphasis placed on the areas that are important in the early phases of the program.

The planning for the FAE II program might have been smoother if mention only of certain specialty areas had been made just to indicate recognition of the importance of the area and to identify the time frame when a complete plan would be generated. When this type plan was attempted, it became obvious that each specialty group felt that a complete plan should be prepared, and every conceivable detail specified. This special interest pressure was resisted. The sections of the plan concerned with Facilities, Logistics, Human Factors Engineering/Personnel, and Training/Support were substantially, though not sufficiently, reduced. The threat always existed that any specialty group resisting supposed underemphasis of that particular specialty could jeopardize the desired schedule, if the group were so inclined.

In retrospect, it appears that the section on Intelligence/Threat should have been deleted from the FAE II Joint Development Plan in its entirety. The original entry by the intelligence group was a 29-page document containing very important and interesting target information but this information had no value to the readers of a development plan. Also, this entry would have raised the security classification of the Joint Development Plan, thus causing obvious difficulties. The intelligence information is more appropriate to the Requirement Document.

The Joint Development Plan should be written as a working document and reflect the maturity of the development stage. Key issues and planned methods of resolution should be addressed. As the program progresses, additional sections should be expanded, as necessary, to insure full consideration. Attempts to make the JDP all-encompassing from the outset not only wastes time but could create a document that loses relevance with time.

Considerable attention was devoted to the drafting of an acceptable, and workable, management structure. At the time of Joint Development Plan approval, the FAE II Project Manager was located at NWC and was acting for NAVAIR within the framework of the approved JDP and other controlling Navy regulations. The relation between NWC and the Armament Division of NAVAIR that this arrangement reflected had been established for a long period of time. The participants had demonstrated the ability to work with efficiency and success. At the time of a JDP update in 1975, a change in location of the Project Manager Office was directed by NAVAIR. This direction was brought about by a reorganization within NAVAIR, and AIR 532 was designated Program Management Office for all conventional munitions. The effect on the previously established FAE II Project Office at Naval Weapons Center was a name change. The Project Office became the Project Team; the NWC Project Manager was redesignated the NWC Project Team Leader. The Air Force Deputy Project Manager remained with the NAVAIR Program Office, but was located at NWC until

his reassignment. A new Air Force Deputy Project Manager was recently assigned but is located at Eglin Air Force Base.

The Deputy Program Manager position was established to collocate at the Naval Weapons Center with the Program Manager. The Air Force and Navy had different perceptions of the role of the Deputy. The Navy viewed the occupant of this position as a Deputy who would in fact, act for the Program Manager in his absence. This Deputy's primary duties, though, (as directed by the Air Force) were to interface with the Air Force to ensure timely satisfaction of Air Force requirements. The Navy assumed that the Deputy would report to the Navy Program Manager in the same manner as other members of his staff. In fact the Air Force never intended that the Deputy report to, and work for, the Navy FAE Project Team at the Naval Weapons Center. The Air Force agreed with the Navy in that the Deputy's primary purpose at the NWC Program Office was to assure USAF requirements were met. The Deputy was authorized direct official contact with his parent organization at Eglin Air Force Base. Copies of all correspondence were made available to the Navy Program Office. The unique difficulties this situation generated arose from the fact that a competitive development was still underway. Transmission of NWC test results to Eglin Air Force Base often resulted in the generation of differing conclusions drawn from these results. This situation was viewed as a serious problem by the Naval Weapons Center FAE Team. The correspondence issue was formally resolved, and the autonomy of the USAF Deputy was reaffirmed. The Air Force Deputy Program Manager is now free to convey information to pertinent Air Force offices concerning any program matter deemed appropriate. In like cases, where major impact on the program could result, a Joint Service position should be sought.

PANELS FOR RESOLUTION OF ISSUES

From the onset it was recognized that differences of opinion between the services existed and that ways of resolving these differences must be established. By AMRAD direction, two advisory groups were established: the Joint Development Review Panel and the Joint Technical Review Panel. The AMRAD intended that the development program have joint service provision for addressing technical and managerial problems.

The Joint Development Review Panel consists of equal numbers of representatives from NAVAIR and the AFSC; the Panel is chaired by a Navy representative. The group is convened upon formal request from either the Navy or the Air Force. A unanimous decision by the Panel allows the Project Manager to take direct action on the matter under discussion. Nonconcurrence after deliberation calls for resolution by higher authority through the existing chain of command.

The Joint Technical Review Panel was established to assist in resolving technical issues that predate the establishment of final design baselines for full-scale development. This Panel consists of four representatives each from the Naval Weapons Center and the Armament Development Test Center and is chaired by the senior Naval Weapons Center representative.

RESOLUTION OF BASELINE DESIGN

Although neither the Navy nor the Air Force had demonstrated success by the end of fiscal year 1974, each service had flight test assets. Advanced development was continued through fiscal year 1975. However, as a result of lead service designation, the Air Force terminated fiscal year 1975 contracts, reduced the scope of advanced development testing, and disbanded the Air Force FAE II team.

The Navy assumed that they would be responsible for selection of the best approach, after a review of the Navy and Air Force programs. The Air Force took the position that this was a joint service function to be performed by the Joint Technical Review Panel. The first meeting of the Panel was conducted in April 1975 and the fiscal year 1975 ad-

vanced development programs of both services were reviewed. This review had the goal of establishing a baseline design through resolution of service differences and identification of the best approach to the program. After 3 days of deliberation, the Panel concluded that additional advanced development was necessary to overcome performance limitations revealed through the test programs that had been performed by each service. The Panel specified performance goals for the advanced development tests, identified key questions requiring resolution, and recommended design changes in the advanced development models.

At this review the Air Force insisted that the Navy also complete advanced development previously terminated by the Air Force. After unsuccessful Navy negotiations, an Advanced Development Plan was prepared to include the test of Air Force concepts. This responsibility was viewed as a serious problem by the performing Navy organization. The following excerpt from a memorandum for record expresses the Navy feeling:

> **"It is obvious that the selection of the FAE II baseline design for Engineering Development is thwarted by unintentional internal biases within each service.**
>
> **The Naval Weapons Center believes that the Navy approach provides the more optimum solution to the FAE II problem. The idea of the Navy continuing the development of both approaches until a selection is made is destined to failure no matter how well we perform because any failure is likely to be viewed as a fault caused by the Navy. It is therefore recommended that the Navy provide a substantial sum of money to the Air Force . . . to show good faith, and if the Air Force really believes that their approach is superior they can provide any amount necessary to augment that funding necessary to demonstrating the system . . ."**

This approach was not taken because of funding problems and because the Air Force felt the responsibility for testing candidate approaches should be with the lead service.

The eventual result of completing the advanced development plan was unanimous agreement by the Joint Technical Review Panel on a baseline design.

OBSERVATIONS

A joint service development is often interpreted as a development of an item by two or more services, each of which has significant influence on all aspects of the development. Such an interpretation allows dialogue not only on the basic requirement but on other areas such as determination of the best approach to the job, the materials, contractor selection, and contract monitoring. Such a dialogue, while it can be beneficial, can also cause endless argument on minor matters and lead to potential schedule slippage and higher costs.

The FAE II joint service involvement brought together two strong technical teams that had different opinions regarding the best approach to the programs and different opinions about the criteria for demonstrating weapon feasibility. The resolution of these differences resulted in the program entering engineering development 2 years later than had originally been proposed by the Navy. The question of how much, if any, time and funds were wasted during the 2 year period is probably impossible to answer. Real problems were solved in advanced development—it is difficult to imagine how the cost of solving the problems could have been reduced had the program been in the engineering development phase. Further, the technical risk was judged acceptable to both services.

Experience with FAE II suggests a number of recommendations for consideration in future joint service developments:

1. Factors considered when designating the lead service should include an assessment of the technology and demonstrated performance of the proposed development. (In the case of FAE II, productive interservice competition promoted technology advances. Lead service designation was made prior to the demonstration of a functional model. As a result, Air Force priorities in FAE were reduced and funding reductions forced termination of advanced development. Unfinished

efforts were later completed by the Navy at increased cost.)

2. The terms, such as feasibility demonstration and concept validation, often used to describe the outcomes of advanced development (validation phase), should be described by the participating services in quantitative terms as a prerequisite to the initiation of engineering development. This was not done early on in the FAE II program but was done eventually at a time when hardware assets were minimal and at the risk of rejecting the best approach because of nonsystem related test failure data.

3.Evaluate with care the developmental approach for a program that appears to be the optimum approach, whether it be a joint development or a development for joint service use. Participating services, in the latter approach, would be concerned with satisfaction of the requirements (including cost, performance and schedules), but would not be active on other factors in day-to-day management of the program. Exceptions to this would occur in cases where the participating service was requested to assist because of a special competency. In essence, the lead service would be told the requirements, but not how to accomplish them.

4. Establish a simple agreement relating to issue resolution between services on joint programs. Such agreement could specify:

a. All issues deviating from agreed-upon plans and requirements must be jointly resolved.

b. All other issues can be unilaterally resolved.

Suggestions from the participating service should be welcomed. The degree of attention to be devoted to these inputs should be determined by the lead service.

5. Give full attention to the designation, physical location, duties, and responsibilities of the Deputy Program Manager. Provide procedures for information transmittal. Consider the size of the project before assigning a full-time Deputy at the lead service field activity. Such collocation may not be warranted.

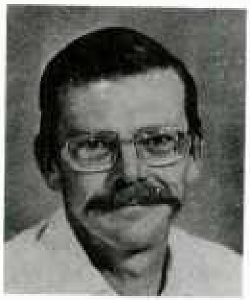
6. Simplify the Joint Development Plan by deleting detailed planning factors that will not be relevant in early stages of the program. Such information should be provided, as it becomes relevant in subsequent revisions when the item is more firmly developed. State only a framework for detailed support plans in the initial JDP. Detailed plans in areas such as training, quality assurance, maintainability, value engineering, configuration management, data management, production facilities, and logistics are not warranted in an initial Joint Development Plan. The framework should state when detailed plans for such areas will be provided. Delete the currently required section on Intelligence/Threat in the JDP; this information is better placed in the Requirement Document.

7. If individual Services intend to compete for the lead, a schedule, mutually agreed upon, should be established for the competition by the competing Services. This action would allow competition completion and a review of the results prior to establishment of the lead Service.

8. Recognize that most less-than-major programs cannot afford the formal requirements necessary for the major programs.

9. Recognize that the Joint Development Plan is usually written long before a baseline design is established, and that cost estimates are uncertain.

10. Establish a corporate memory on joint programs to allow new programs to benefit from previous programs. ☐



Mr. James A. Bowen is Head, Weapons Systems Branch, Naval Weapons Center (NWC), China Lake, CA, where he is responsible for all Navy Fuel-Air Explosive efforts. Mr. Bowen began his professional career at the Naval Weapons Center (then NOTS) in 1955. His early experience was in design and developmental engineering on warheads and solid propellant propulsion systems. He demonstrated the first underwater launch of missiles by means of buoyant encapsulation. As Head, Astro Propulsion Branch, he developed the first prototype missile fluid injection thrust vector control system that was later used on the second stage of the POLARIS A-3.

Mr. Bowen became Head of the Weapons Systems Branch in May 1966 and assumed responsibility for the Navy Fuel-Air Explosive (FAE) technology projects. He later became Program Manager for the first FAE weapon to be operationally deployed by the services.

Mr. Bowen was awarded the American Ordnance Association "Harvey C. Knowles" Award in May 1972 for a major technical contribution related to armament. In the same year he received the Michelson Laboratory Fellow in Management Award for his technical and administrative performance in developing Fuel-Air Explosive technology. Mr. Bowen received his B.S. Engineering from Texas A&M College, in 1955.

Captain Ronald S. Fry is the Air Force Deputy Program Manager, FAE II Joint Service Program. He is assigned to the Armament Development Test Center, Deputy for Armament Development, Munitions Systems Program Office, Eglin AFB, FL. Captain Fry has had more than 7 years research experience in fuel-air explosive technology.

Captain Fry received his BSE degree in 1969, his MSE degree in 1970, and his Professional Engineering degree in 1975. All three degrees were awarded by the University of Michigan. In graduate school he specialized in combustion and shock wave propagation phenomena directly related to the FAE problem. Captain Fry's initial active duty assignment (1974) was as a project engineer on the Air Force FAE technology effort discussed in this article. He participated in many of the Joint Technical Review Panel meetings that shaped the validation phase of the FAE II development. Shortly following program transition to full scale development phase Captain Fry was assigned to his current position.

Captain Fry is author of numerous technical articles on the subject of FAE, including publications in the American Institute of Aeronautics and Astronautics Journal and the internationally recognized Acta Astronautica and the Fifteenth Symposium (International) on Combustion. Captain Fry graduated from the Air Force Squadron Officer School, Class 77-B, 1977, at the top third of his class.

Computer System Simulation:

A Design Evaluation Tool

by

Major Robert Steven Feingold, USAF

In an important sense, computer system simulation studies are to the evaluation of computer system design what wind tunnel tests are to the evaluation of air vehicle designs. For years, Program Managers responsible for aeronautical system developments have relied on the results from wind tunnel tests. The same opportunities for evaluating and reducing the development risk associated with embedded computer systems are now available to Program Managers through the use of computer system simulation.

PART I

Introduction

The increasing complexity of weapon systems is ever present in military system procurement. Complexity affects development costs, development schedules and, once the system is deployed for use, operational support costs. Complexity has a significant impact on user-stated system performance goals. Generally, as design complexity increases, so does the level of effort required to meet user needs–on time and within budget.

Among the most complex weapon systems are those that contain embedded computers. An embedded computer system is a collection of hardware and software that serves to support an overall weapon system mission. Embedded computers are used to process radar track inputs, drive display devices, control propulsion systems, and supervise the launching of various categories of ordnance. Computers are employed directly by combat elements to process intelligence data, to route command message traffic, to solve complex trajectory problems, and to assist in controlling the movement of supplies and replacement parts to front line units. Because computers can solve mathematically-stated problems rapidly, embedded computer systems will continue to exert great influence on weapon system design decisions and on weapon system complexity.

The development process for computer hardware is well understood and for the most part is practiced with success. The same cannot be said for computer software. Of several embedded computer system developments that have experienced problems, the majority of the problems can be attributed to software development management issues.

Like hardware, computer software goes through concept, validation, full-scale development, and production-deployment phases. Figure 1 shows this development cycle. The major concern in the concept phase is the derivation of the computer system performance and support requirements in consonance

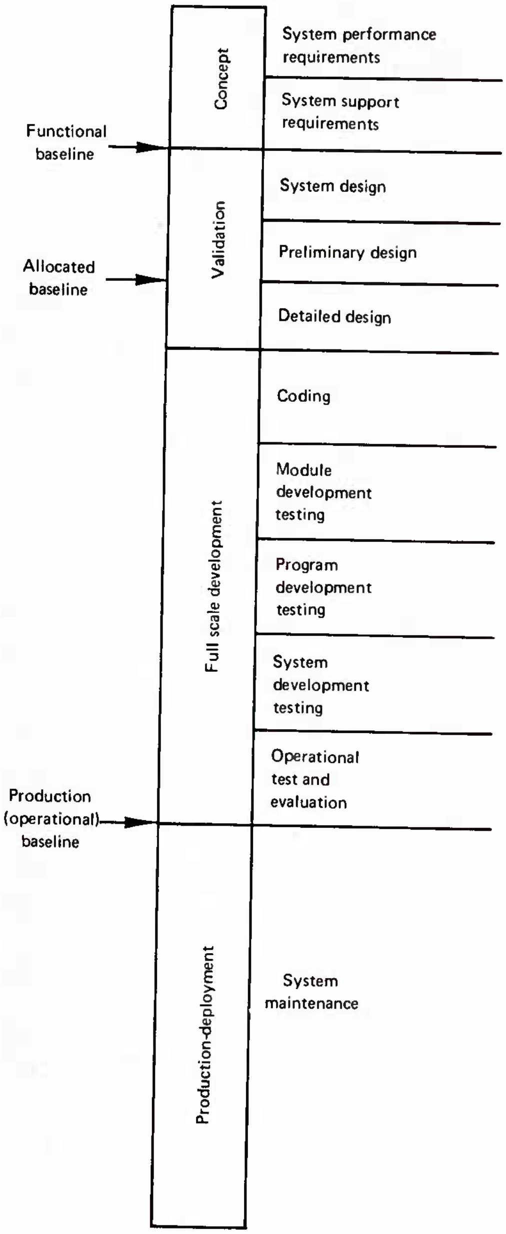


Figure 1, Software Development Cycle

with the overall mission requirements.

In the validation phase the design effort is of major concern. It is in this phase that proposals for hardware and software configurations are brought forward and evaluated against user requirements. In the validation phase, design decisions are made that determine how well the computer system will meet its performance goals.

In full-scale development concentration is on the acquisition of hardware and the programming of software in accord with the design selected in the validation phase. Full-scale development is a lengthy phase that involves the testing of hardware and software in a controlled environment.

The production-deployment phase starts after the operational baseline has been established. Software can be reproduced easily for deployment. Hardware must proceed through the usual manufacturing and qualifying steps.

Although the development cycle follows the traditional approach, the potential for encountering major software development problems remains high. Problems frequently occur as the result of decisions made early in the development cycle. Historically, the principal reason given for hardware-software development problems is the low level of management attention given embedded computer systems by government program offices. Often the effort devoted to hardware-software design trade-off studies (in the validation phase) is not sufficient to identify potential problems.

One reason for not devoting adequate resources to computer system hardware and software trade-off studies is lack of appropriate tools. Software design trade-offs are difficult to study before software is prepared or before hardware becomes available. The computer system designer often makes hardware configuration and software implementation decisions based on experience. The consequence often is an imbalance in total system performance. The embedded computer system may fail to support the weapon at the desired level of effectiveness.

The primary goal of this paper is to present a computer system design evaluation methodology appropriate for the validation phase. The methodology involves user, designer, and developer in an iterative and interactive design evaluation activity. The methodology relies on the operations research technique of system simulation. Simulation programs represent relevant system and subsystem relationships in model form and can be used to evaluate the cost, schedule and performance impact of proposed designs in response to user-stated requirements.

A "hypothetical situation" is used to illustrate how computer system simulation can be employed in the acquisition process. This approach is intended to dramatize the process by permitting an indepth look at the computer system simulation technique. The objective is to show how this technique can be used by a program office responsible for an embedded computer system development.

PART II

Computer System Design Evaluation Methodology

Before delving into the details of the computer system simulation technology, first examine where computer system simulation fits into a conventional design evaluation process.

The design evaluation process discussed consists of six steps, related as shown in Figure 2. The process is iterative. The design evaluation team can use the results from experiments to develop additional design choices and to suggest changes to existing user requirements. This iterative process, however, cannot go on forever. Time is usually the major constraint. More important, there is a limit to the sensitivity that model-based evaluation techniques can show, given gross statements of requirements and design options. The evaluation must culminate in a set of design decisions to be carried forward for implementation into hardware and software.

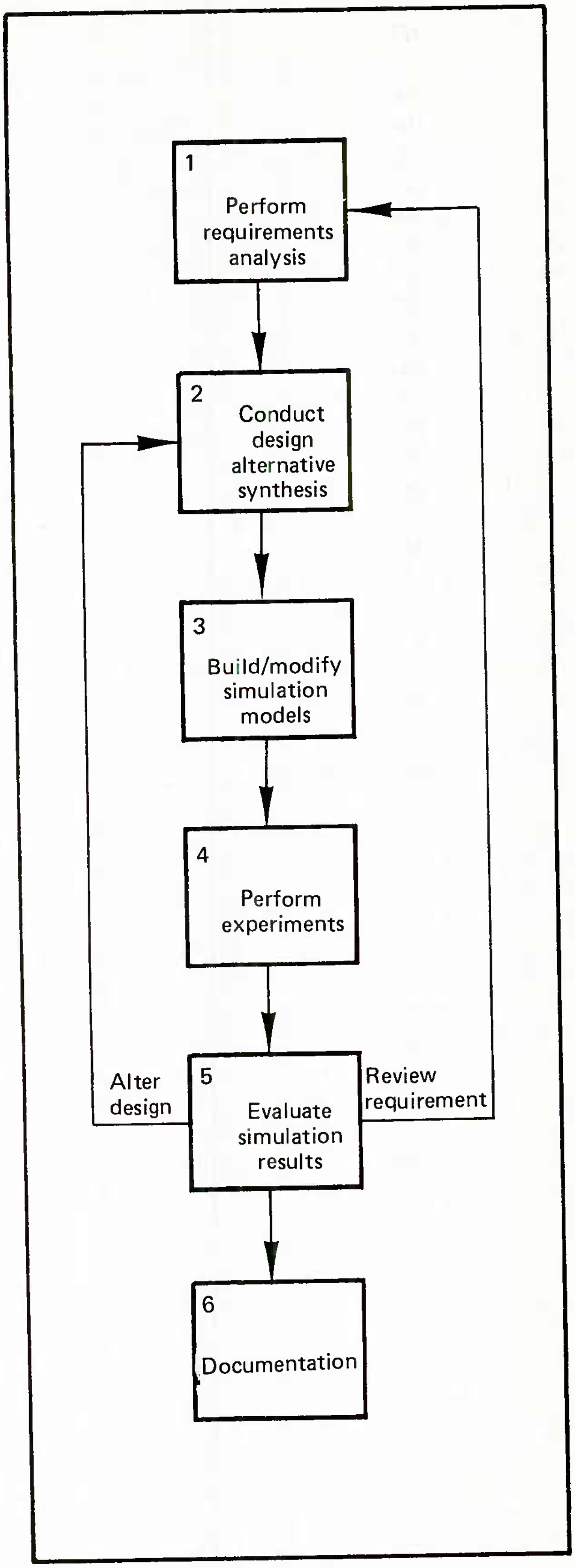


Figure 2, Design Evaluation Process

REQUIREMENTS ANALYSIS—STEP 1

An understanding of the user's objective is basic to the success of the design process. Often achieving this understanding is difficult. The path the designer follows frequently is cluttered with user jargon and user design biases. To overcome these and similar problems, I advocate the formation of user-designer-developer teams that can function throughout the entire process. Clarification of user intent and developer capability at an early stage usually contributes to overall success. Such clarification reduces the number of false starts and shortens the design approval process later.

The output from Step 1 is an understanding of the problem, some insight into the feasible set of solutions, and, most important, the establishment of an integrated user-designer-developer team that can function effectively throughout the remaining five steps.

DESIGN ALTERNATIVE SYNTHESIS—STEP 2

Synthesis of system design alternatives is a creative process that combines the designer's understanding of the requirement, his abilities, his education and his past experience. Alternative evaluation takes place at this step in the process. Although many proposals will be made, only a few will be worth further study. Judgment is essential to eliminate proposals that do not merit further consideration. In Step 2, the judgment is supplied by user representatives working in conjunction with the system design and development specialists.

In the past, design evaluation was accomplished using techniques that did not always consider the complexity of modern computer systems. In many cases this could not be avoided because economical evaluation techniques were not available for doing indepth analyses, nor were there any techniques sufficiently responsive to the designer's need to provide quick and accurate answers to design trade-off questions. The computer system simulation approach is both available and responsive.

MODEL BUILDING—STEP 3

The process of model building satisfies two critical requirements. First, model building permits the user-designer-developer team to articulate a combined knowledge of requirements and design alternatives into a physical entity. The model is understandable and can be subjected to intensive analysis.

The second major requirement to be satisfied during model building is the development of a responsive tool which is useful throughout the remainder of the process. The model, if constructed properly, extends the intellectual abilities of the design evaluation team by providing an insight to system component relationships, rather than only masses of numbers to analyze. The design team can try combinations of design and requirement variables to arrive at an understanding of what the proposed system will do and how it will behave under a variety of circumstances.

A language useful for building models for the application being described is called the Extendable Computer System Simulator II (ECSS II). This language was developed by the RAND Corporation for the US Government, under sponsorship of the Federal Computer Performance Evaluation and Simulation Center (FEDSIM) and the General Services Administration. The ECSS II is used here because it satisfies the two modeling requirements: understandability and responsiveness. The ECSS II has an English-like syntax and provisions for compact descriptions of computer elements (hardware and software). The flexible and extendible ECSS II can be modified and is economical to run. Report generation capabilities and data collection facilities are most acceptable.

EXPERIMENTS—STEP 4

Experimental runs made with a model should be designed to explore as much of the design and requirement response surface as possible. An exhaustive search is impossible. Experiments should be performed that allow the design evaluation team

- to validate the model, and
- examine system performance behavior relative to changes in sensitive design variables.

Model validation is a major subject. A model should be validated to a point where its behavior can be explained by either a model coding error or a phenomenon which the modeler can reasonably expect from the actual system. The outputs of the model may be considered valid if they are explainable without massive contortion of facts or logic.

The simulation experiments provide numerical data on the performance of a proposed system, given input design variables and a simulated operational environment. A series of experiments are usually run, each with logical variations made to the input parameters. After the experimental phase, the outputs are correlated with the changes in design input. Thus, a better understanding of system behavior is achieved.

For most computer system simulation models, there are three classes of input variables:

- Variables that represent hardware options such as processor speed, memory size and input-output capacity.
- Variables associated with software design options. In this class are various possibilities for implementing application software, memory management techniques, and multiprogramming control schemes.
- Variables related to the operational environment. For example, a message handling system operates in an environment where message arrival rates and sizes are quantified, and specifications for message response times are given.

The outputs from the experiments carry onto the fifth step of the process: Evaluation of simulation results.

RESULT EVALUATION—STEP 5

The fifth step in the process is intended to result in one of three possible decisions. If the results of the experimental runs indicate that the proposed designs are inadequate, the team must go back to Step 2 and try to develop new designs. The processes in Steps 3, 4, and 5 are repeated. This situation is a common occurrence. Often a system design, on paper, appears to satisfy the requirement but turns out to be a failure. Usually this is because of the complex resource demand pattern produced by embedded computer system software. When a simulator conclusively shows that a problem exists, the design evaluation team must try to develop new designs.

The second possible decision is closely related to the first but differs enough to justify separate treatment. After several iterations, it may become clear to the design evaluation team that the state-of-the-art does not provide a design feasible for satisfying the requirement. In this case, the design evaluation team might challenge the requirement by using the model to evaluate the effect of a relaxed requirement on the design choice. Full user participation in this kind of exercise is mandatory. Modifications made to the requirement inputs of the model are for experimental purposes, to determine the trade off of system cost to changes in requirements.

The third possible decision represents the end product of the process to this point: the selection of a feasible system design. Through use of the model, the design evaluation team can select one or a small number of designs worthy of further consideration. Given such a determination, the design evaluation team can move to Step 6.

FINDINGS AND DOCUMENTATION—STEP 6

The final step, although it may appear anticlimactic, is important. The design evaluation team must report findings. The findings become the basis for seeking approval to continue work. This documentation must be clear on a number of key points. First, the process used to translate the requirement into model inputs must be absolutely clear. Second, the documentation must clearly and completely identify all of the assumptions for each of the three classes of input that

went into the fabrication of the model. Third, the model must be described so all the previously identified assumptions are clearly discernible within the model representation. Fourth, the data collected from each experimental run must be defined so that an accurate interpretation of numerical values can be made. Fifth, the experimental design must be described and justified. Finally, the results from each experimental run must be described in terms that support the conclusions and recommendations of the design evaluation team.

These documentation requirements may seem excessive; however, computer system simulation is viewed by some as suspect. In the past, full disclosures of methodology were not made, and it was not apparent how the recommendations were derived. There is no such thing as "hard simulation data" upon which high dollar decisions can be made without some risk.

PART III

Illustration

HYPOTHETICAL REQUIREMENT

To illustrate the use of computer system simulation in the embedded computer system design evaluation process, a hypothetical situation (hypothetical in terms of the numbers developed and assumptions made) is presented. In this situation the first two steps of the design evaluation process are illustrated: requirements analysis and design alternative synthesis. The basis for the illustration is a military system design problem. A typical user requirement and one design proposal is presented. Although only one design proposal is discussed, the methodology can handle any number of design proposals.

Assume a tactical field activity needs an improved capability to process information on potential tactical targets. Next assume that the activity must provide responsive reports to air component commands on possible tactical air missions that should be flown against the targets. Specifically, the field activity is to search lists of known targets, update these data, and display those targets that have attributes corresponding to the input search arguments.

In addition, timely printed reports that display target data in a variety of ways are to be obtained. Report formats must be flexible to satisfy new requirements encountered in the field.

In general terms, three capabilities are required:

- An ability to input target data to the system for retrieval later;
- An ability to search and update the data base for records satisfying a number of search input characteristics; and
- A facility to provide printed reports of previously conducted data base searches.

Also, the user desires to record all system transactions in printed form so that hard copies of all data base changes and accesses will exist.

Based on his knowledge, the user provides additional details of his requirement. First, he defines a system encounter to be any series of interactions between a human operator and the mechanized system. Example: a typical data input encounter consists of an input stream of characters representing target data. The output is a signal from the system that the target data are safely stored in the data base. Second, the user provides information on the number of encounters that the system is required to process per hour. Third, the user provides an indication of the number of characters of input associated with each encounter category. Finally, some indications as to the volume of print characters needed to complete each encounter are provided.

In Table 1 the general requirements are summarized for all encounter categories. By themselves these requirements are not sufficient to develop design alternatives, let alone build a simulation model. Assume that additional information exists that helps refine

the user environment to a detailed level and allows a design (and model) to be proposed. For example, it is safe to assume that each encounter in reality is a series of man-machine interactions consisting of a human stimulus input, system processing, and final output response. Further, assume that the system operator interfaces with the equipment through a keyboard cathode ray tube (CRT) display device. By implication, the operator must key inputs at a given rate. At a specified reading speed, the outputs provided on the CRT are to be examined. The operator must then mentally review the actions that have been taken and the actions to be taken before keying the next interaction stimulus. Finally, assume that the data base is stored on a random access device, say a disk, that is accessed a number of times to satisfy each man-machine interaction.

Table 1, General User Requirements

Encounter category	Encounters per hour	Input characters	Output print characters
Data input	30	80 - 1,000	480 - 6,000
Data base search and update	12	40 - 200	4,800 - 24,000
Report generation	6	30 - 45	96,000 - 144,000

Table 2 provides the numberical values associated with these detailed assumptions. Table 3 is a list of those qualitative assumptions needed to complete the background material.

HYPOTHETICAL DESIGN

One design is discussed here to illustrate the design proposal synthesis process.

Table 3, Qualitative Assumptions

1. Incoming material representing an encounter (i.e., data for input, search argument values, etc.) have interarrival times drawn from an exponential distribution with a known mean.
2. Encounter categories are of equal priority.
3. The system operator(s) must LOG ON to the system for each encounter (to satisfy security procedures).
4. Every stimulus from the CRT requires a response (to the CRT).
5. All encounters are logged. Some encounters produce a printed output(s).
6. Response time: the interval from arrival of encounter material to time last line of output is printed.
7. The system should be compact, consist of a minimum of parts, be reliable, and easily maintainable in the field. The technology must be within the state-of-the-art.

Table 2, Quantitative Assumptions

Encounter category	Repetitions per encounter	Average key stroke time (3 characters per second)	Response read time (500 characters per second)	Think time (seconds)	Data base accesses
Data input	2 – 25	26 – 333	10 – 120	10 – 125	4 – 50
Data base search and update	2 – 10	13 – 66	5 – 24	15 – 70	100 – 1,000
Report generation	2 – 3	10 – 15	4 – 6	10 – 15	40 – 120

HARDWARE

The system will consist of a central processing unit that has:

- A memory
- A multiplexor interface channel to the keyboard-CRT devices and the printer, and
- A burst mode interface channel to the disk devices that will hold the data base.

Since it is required that the system consist of state-of-the-art components, the capabilities of each subsystem will be restricted.

The design proposal considered here is shown in Figure 3. The names given to each class of components appear later in the model. Device characteristics are shown with each system component. The devices called C.PATH, P.PATH and D.PATH are names given to entities over which simulated data flows. For example, C.PATH serves the cathode ray tube (CRT) to CH1 path while D.PATH serves the DISK to CH2 path.

SOFTWARE

Hardware in a computer system is of no use without software and software must be designed in appropriate detail. The following assumptions simplify the illustration. First, consideration is not given to operating system overhead. The assumption is made that overhead is accounted for within the application software. Second, each major category of input is served by a different program that must be in the central processing unit (CPU)

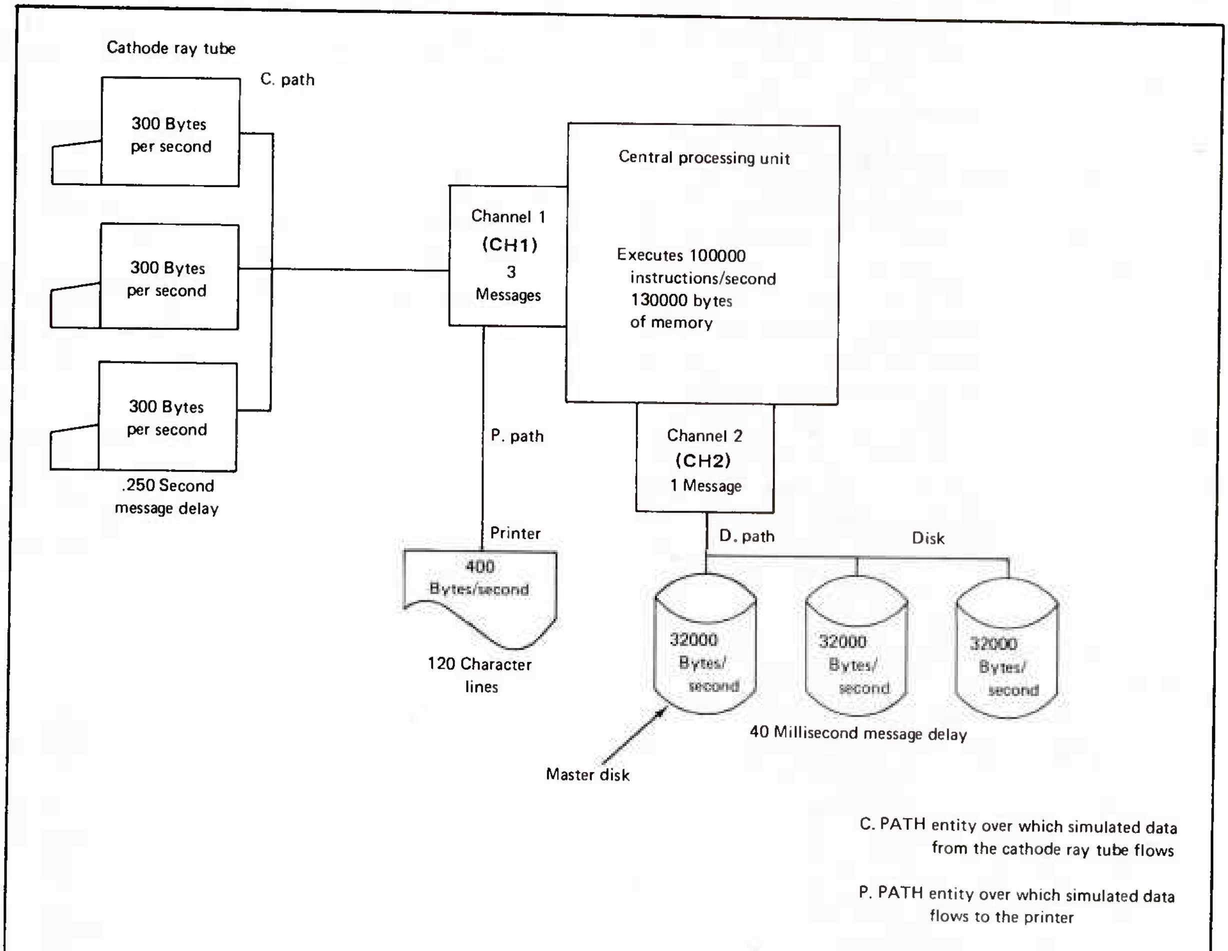


Figure 3, System Design Configuration

memory for the interactions between man and machine to take place. Third, the system supports multiprogramming. Many programs can reside in CPU memory at one time and compete for the CPU and other system resources. Finally, there is a separate program that produces a hard copy printout (printed sheets of paper) from files stored on disk. Under this arrangement each program that produces a hard copy printout places the data on disk for later printing. This process is called spooling and is used often to control access to printing devices.

Elaboration is required for each of the processing categories. The actions of the operator are shown in Figure 4. First, the operator receives the material with which he must work. The material may be new input data, information for searches or updates, or parameters for a required printed report. The operator LOGS ON and waits for the system to indicate access to the necessary system resources. Next, the operator performs a series of machine interactions until the work is complete. The operator then requests the machine to produce a printed product. Next the operator LOGS OFF. Because it is likely that additional encounter material is waiting, the operator will resume performance of a like task.

The software process supporting the Data Input encounter category is shown in Figure 5. First, the LOG ON is performed and a signal to proceed is given the operator. Each time the operator provides an input, the program places the data on disk, updates the data base index, and displays a response on the operator's CRT. When all interactions are complete, the LOG OFF process is performed.

The Data Base Search and Update encounter process is more complex. See Figure 6. After performing the LOG ON process, each operator input is scanned and used to control the search and update of the data base. Once again, when the interactions are complete, a LOG OFF is performed.

Figure 7 is a flowchart of the Report Generation process. The program interprets operator inputs, retrieves data from the data base, organizes these data into the appropri-

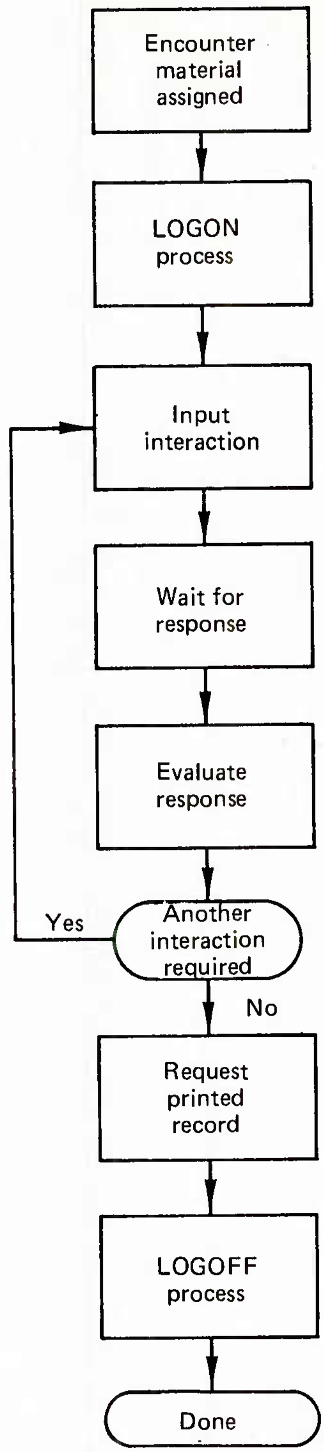


Figure 4, Operator Behavior

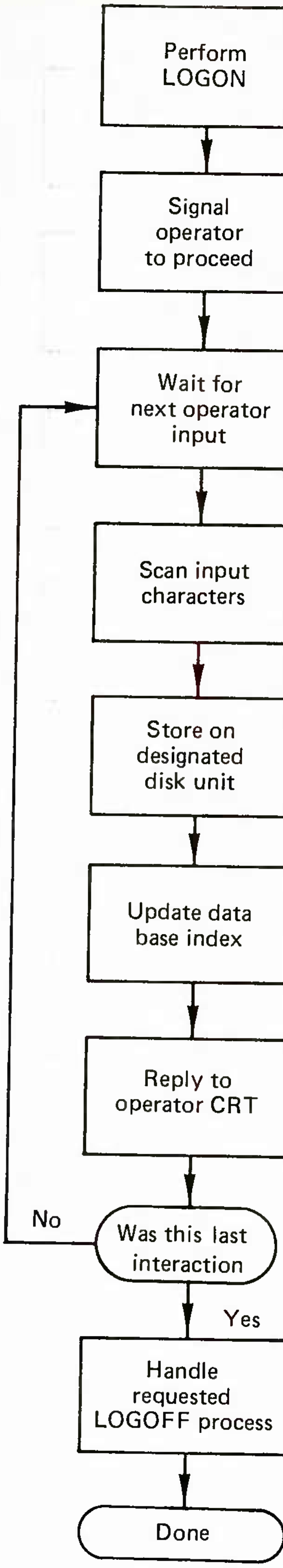


Figure 5, Input Target Data Process

ate report format, and stores the report on the output spool file for later printing.

One final process completes the software program set. The Print Spool Program, shown in Figure 8, produces all the printed products for the system. The program is assumed to operate in a batch mode, or as a background process, and can serve a system with multiple printers. This design feature enables the program to later request a printout from the system that prints, one by one, the lines contained in the output spooling files.

INITIAL TIMING STUDY

Initial timing estimates to determine the response time characteristics of the system can now be made. First a few assumptions are made about instructions executed per program as well as input-output requirements for each program. The assumed instruction counts are given in Table 4. These numbers represent our informed estimate of what is required to accomplish each process. Experience and knowledge of commonly used algorithms form the primary basis for the low and high estimates.

Table 4, Process Instruction Counts (instructor/encounter)

Encounter category	Low estimate	High estimate
Data input	19,980	48,500
Data base search and update	1,057,200	10,156,200
Report generation	565,200	842,800

Table 5 shows the low and high estimates for input and output times. Within a process there is only one input-output (I/O) function performed at a time. The I/O is never overlapped with instruction execution. The values in Table 5 include all I/O for each process. Again, I/O associated with printing is included with each of the three processes. The precise flavor of the values shown in Table 5 results

from expressing I/O in seconds rather than in characters per encounter. This is necessary because the CRT, DISK, and PRINTER transfer characters at different rates.

Table 5, Input-Output Timing

Encounter Category	Low time estimates (seconds/ encounter)	High time estimates (seconds/ encounter)
Data input	3.194	36.685
Data base search and update	21.83	81.485
Report generation	243.808	368.925

To complete the timing study, account for operator think time that is not overlapped with any machine process. This accounting can be complex but can be simplified by assuming that for the three interactive processes, think time is 20 seconds, 20 seconds, and 15 seconds respectively. In summary, the average timing estimates shown in Table 6 are obtained by finding the mean of the low and high timing estimates. This is reasonable if instruction counts, data base accesses, and transaction character sizes for I/O are drawn from uniform distributions and if the low and high values given in Tables 4 and 5 are used as parameters.

Table 6, Timing Summary (average seconds per encounter)

Timing element	Data input	Data base search and update	Report generation
Execution time (1000000/second)	.342	56.067	7.0400
Input/output time	19.393	51.657	306.366
Think time	270.0	120.0	25.0
Total	290.281	227.724	338.406
Average response time		285.470	

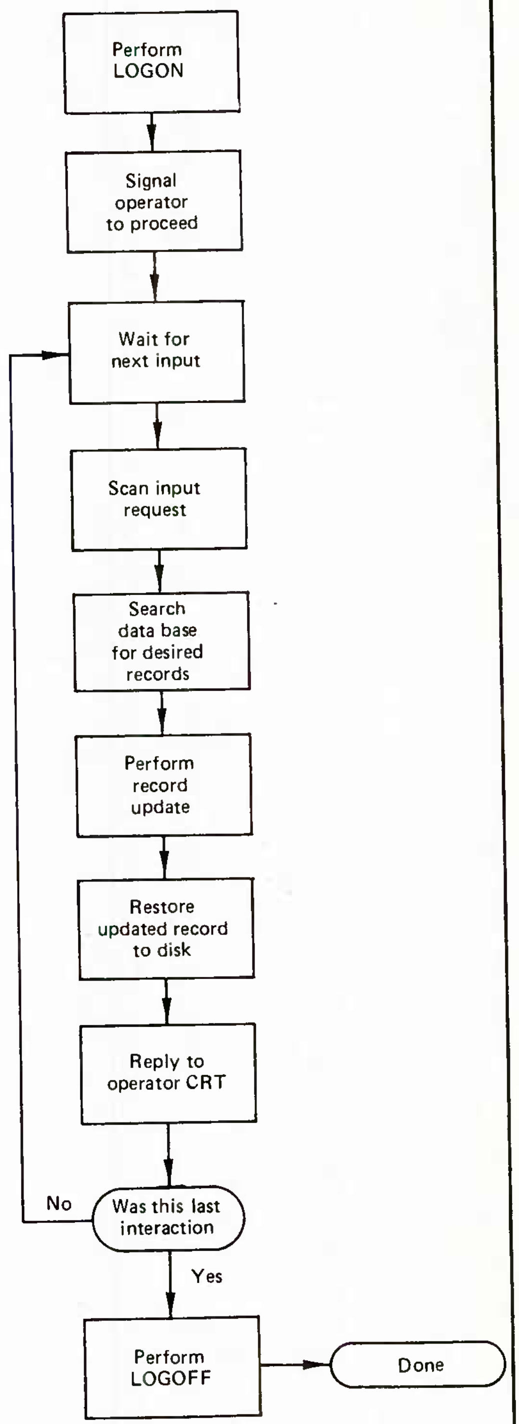


Figure 6, Data Base Search and Update Process

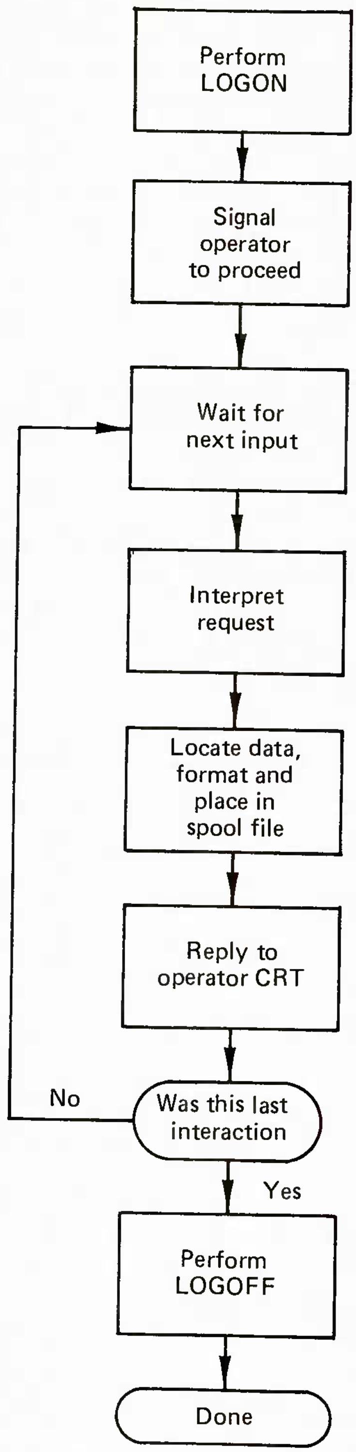


Figure 7, Report Generation Process

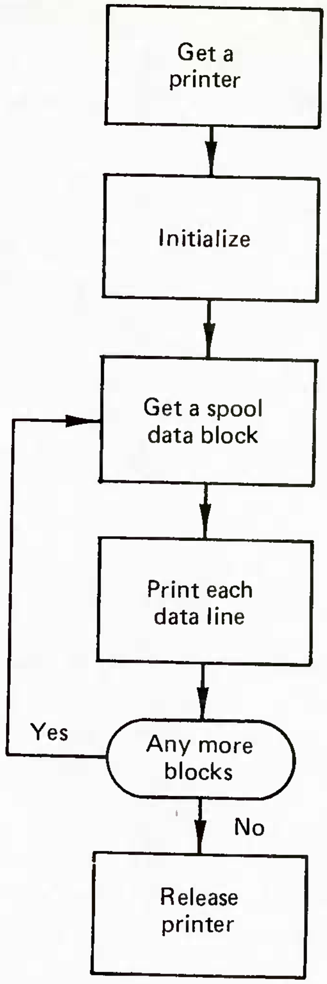


Figure 8, Output Spooler Process

Analyses as performed here are common, and for simple systems are adequate. This type analysis does not account for all resources needed to process an encounter. For example, the analysis discussed does not indicate that the design value of 130,000 bytes of memory is adequate for the combination of processes. Further, time could be lost as each process waits for resources assigned to other processes. Queues can develop. First, there are four devices on CH1 that can process only three messages concurrently. Second,

there is one CPU. A maximum of four programs can request this resource at any given time. Third, the DISK devices must be accessed one at a time. Each of four programs requesting the CPU can have DISK I/O requests. Finally, there is only one printer, yet three processing programs can be generating print outputs.

Looking at the design as a system of queues is an approach for analyzing the impact of potential resource contention problems. A mathematical solution to these queueing models often requires simplification that could result in assuming away the problem. Simulation is required because the interactions between resources required and resources available are highly complex.

PART IV

Modeling and Experimentation

In Part I, I stated the primary purpose of this paper: to present a computer system design evaluation methodology appropriate for the validation phase of an embedded computer system development. This purpose precludes a long treatise on modeling languages, modeling techniques, and simulation strategies. The characteristics of the model used in this project are delineated in the study paper on which this article is based.*

The model is written in ECSS II and consists of four sections. Each section performs a descriptive or an operative function in the simulation. Persons desiring to examine the construction of the model will be interested in the basic study.

EXPERIMENTATION PLAN

Experimentation can be an extremely complex process even with a simple simulation model. Hence ground rules were established which drastically narrow the scope of experimentation. First, the parameters that describe the requirement are kept constant, although the simulation program permits these variables to be input at model execution time.

Table 7 contains a complete list of the requirement parameters and the values are given in the order of input to the model. In addition, certain design parameters are kept constant. The values of the design parameters are given in Table 8.

The second simplifying ground rule states that only hardware design characteristics such as memory capacity, quantity of CRT used, quantity and speed of printers, and the central processing unit (CPU) execution rate will be varied from one experimental run to the next. These values are input to the simulation through the SYSTEM DESCRIPTION section of the model. Table 9 gives the range of values over which experiments are run.

Table 7, Baseline Requirement Parameters

Parameter	Data input function	Data base search and update	Report generation
1. Stimulus input Character stream (Characters)	40	20	15
2. Think time (Seconds)	20	20	15
3. Maximum no. of interactions	25	10	3
4. Minimum no. of data base accesses	2	50	10
5. Maximum no. of data base accesses	2	100	20
6. Mean encounter interarrival time (seconds)	120.	300.	600.

*Robert S. Feingold, "Computer Design Simulation: A Design Evaluation Tool," Study Report, PMC 76-1, Defense Systems Management College, Fort Belvoir, VA , 1976. (Available from NTIS and DDC, Acquisition No. AD A026387)

Table 8, Baseline Constant Design Parameters

Parameter	Value
Length of simulation run	3600 seconds
Data input program core size	15000 bytes
Data base search and update program core size	60000 bytes
Report generation program core size	30000 bytes
LISTOFF program core size	10000 bytes
Data base record size	2000 bytes
CRT screen capacity	1920 bytes

Table 9, Range of Major Design Parameter Values

Parameter	Low	High
Number of CRT	3	8
Instruction execution rate (ins/second)	100000	200000
Memory capacity (bytes)	130000	260000
Number of printers	1	2
Printer speed (lines/minutes – 120 bytes/line)	200	600

The final simplification involves the performance measures used to evaluate each experimental run. If anything, a simulation provides too much performance data and often is precise to the fifth decimal position, even though its basic accuracy may be questionable. The principal performance measure is the average response time for each encounter category. Response time is measured in seconds and consists of two components: time spent by encounter material entities in a queue prior to being worked on by a system operator and, time spent in processing the encounter material including print processing. The total average response time is reported for each category along with the average total response time across all categories.

Certain other performance measures must not be neglected. These measure performance relative to the utilization and queueing characteristics for the various computer system resources. Accordingly, we look at measures associated with the CRT, CPU, PRINTER, PATH, and memory devices.

In all, twelve experimental runs were made as part of the study on which this paper is based. A partial evaluation followed each run to determine the set of inputs appropriate for the next run. As stated earlier, experimental strategy is not the principal topic of discussion, so all experimental results are presented at one time.

Experimental Results

To begin, look at the results from the baseline design. The initial timing study predicted an average response time for the three encounter categories of 290.281 seconds, 227.724 seconds, and 338.426 seconds, respectively. With this in mind, Table 10 reveals a startling result: a response time of 1640.0 seconds.

Why such results? To answer this question look at the detail performance measures given in Table 11. First, waiting time in the encounter material queue is high at 1086.8 seconds. Given that the average response time is 1640.0 seconds, the average wait time in the encounter material queue accounts for more than 66 percent of this figure. Second, the table shows that CRT utilization is almost 100 percent and the central processing unit is busy over three-quarters of the sampling

Table 10, Baseline Design: Simulation Results Response Times (Seconds)

Measure	Data input function	Data base search and update	Report generation
Queue time	1339.1	492.6	352.7
Internal time	481.6	1357.0	897.1
Total time	1820.7	1849.6	1249.8
Initial prediction	290.3	227.7	338.4
Average response time			1640.0
Predicted average response time			285.5

CRT = 3
KIPS = 100
MEMORY = 130000
PRINTERS = 1/200 LPM

Table 11, Baseline Design: Simulation Results Performance Measures

Measure	Value
CRT utilization (percent)	99.3
Encounter material queue (EMQ) length	19.0
Wait time in EMQ	1086.8
CPU utilization (percent)	75.8
CPU queue (CPUQ) length	.7
Percent CPUQ empty	56.7
Printer queue (PQ) length	.564
Wait time in PQ	101.5
Memory utilization (percent)	77.7
Memory request queue (MRQ) length	.448
Wait time in MRQ	37.5

Table 12, Experimental Runs: Simulation Results—Performance Measures

	EXPERIMENT										
	1	2	3	4	5	6	7	8	9	10	11
CRT, quantity	6	6	6	6	6	6	6	6	6	6	8
KIPS	100	100	100	100	150	150	150	150	150	150	200
Memory size	130	260	130	260	130	260	130	260	130	260	260
Printers, quantity	1	1	2	2	2	2	1	1	2	2	2
Printer speed	200	200	200	200	200	200	600	600	600	600	600
CRT UTIL. (percent)	93.3	90.7	90.3	93.8	90.1	93.3	91.3	92.6	93.0	93.8	88.7
EMQ length	5.2	12.3	8.4	7.5	10.5	5.3	7.7	2.7	6.6	9.1	2.93
EMQ wait time (seconds)	296.3	707.0	481.7	430.9	603.1	301.9	442.0	155.7	379.6	520.0	167.4
CPU UTIL. (percent)	77.4	90.0	81.5	85.8	71.1	80.6	67.7	72.8	93.3	70.5	89.1
CPUQ length	.73	2.28	.96	2.57	.51	2.36	.54	1.69	.60	1.87	4.09
CPUQ empty (percent)	53.4	28.4	47.3	27.2	63.4	35.3	64.1	46.5	62.0	47.1	19.1
PQ length	3.16	3.40	.18	.96	.08	1.25	.21	1.49	.00	.18	1.50
PQ wait time (seconds)	284.3	408.2	16.9	86.2	7.5	88.3	17.4	105.8	.09	17.6	110.5
Memory UTIL. (percent)	87.4	65.4	88.5	69.4	89.5	69.6	87.1	73.0	86.4	60.2	80.4
MSQ length	1.96	0.0	2.36	0.0	2.07	.09	1.63	.09	2.24	.11	.27
MRQ wait time (seconds)	89.1	0.0	106.2	0.0	91.1	3.2	63.2	3.1	94.0	4.8	9.7
Average response time	1039.6	1581.6	1115.0	1024.8	1184.4	923.7	939.2	655.5	927.0	1017.1	889.0

EMQ = Encounter material queue
CPUQ = CPU queue
PQ = Printer queue
MRQ = Memory request queue

interval. It appears that the system needs more CRT devices to increase the level of concurrent processing.

Apparently the initial estimate was faulty, because it was assumed that contention for computer system resources would be minimal. However, contention is clearly evident. The data shows that the CPU queue (CPUQ) is empty 56.7 percent of the sampling interval and the length of this queue averages 0.7, a small yet significant number. Waiting time for memory averaged 37.5 seconds for each memory request. This delay represents approximately 4 percent of the average internal processing time. A similar analysis using the waiting time to start printing figure of 101.5 seconds yields a percent of average internal time equal to 11.1.

That more CRT are required is clear. Less clear, but apparent, is an indication that memory capacity should be increased along with the CPU execution rate, number of printers and printer speed. But how much and in what combinations?

A complete picture can be made of the experiments run, showing the design changes made and the performance measures obtained. Table 12 provides such a picture. Before examining the numerical values for the performance measures given in Table 12, note the experiments. The only change made to the baseline to get Experiment 1 was to double the number of CRT. Next, the memory capacity was doubled for Experiment 2. Experiments 3 and 4 repeat Experiments 1 and 2 but with two printers instead of one. Experiments 5 and 6 repeat Experiments 3 and 4 but with a CPU execution rate of 150,000 instructions per second instead of 100,000. Experiments 7, 8, 9, and 10 all have a CPU execution rate of 150,000 instructions per second, a 600 line per minute printer, but are otherwise repeats of Experiments 1, 2, 3, and 4. This design explores that portion of the performance response surface which can reasonably be considered state-of-the-art and responsive to the requirement given earlier. Experiment 11 is a run to see the results from a design possessing abundant system resources.

What do these data tell us about the proposed design options? First, there is an interesting anomaly between Experiments 1 and 2. Memory capacity doubles. Yet, with all other design parameters held constant, average response time increases. Close examination shows that in fact there is no anomaly. With more jobs in memory, the CPUQ is longer and, on the average, the CPUQ is less frequently empty. CPU contention is much greater in Experiment 2 because more jobs can be in memory and issue a greater number of requests for the CPU resource. In a like fashion, more jobs processed means more print output produced in a shorter time. This is indicated by an almost two-fold increase in printer queue wait time. The average memory queue length is zero which indicates that probably 260,000 bytes of memory were not needed.

The second basic observation is that Experiment 8 yields the best average response time of 655.5 seconds. This is partially explained by the low EMQ wait time of 155.7 seconds. Further explanation is provided by observing that CPU utilization, relatively speaking, is low, at 72.8 percent. Memory utilization is similarly low at 73.0 percent. Taken together, this indicates that overall system resource demands are best balanced with this configuration. On a relative basis, CPU contention is lower, allowing individual jobs to proceed to an input-output operation and thereby release the CPU resource for other jobs. Progress in using the CPU resource is aided considerably by the 150,000 instruction per second execution rate.

Finally, a major observation must be made. By the very nature of the experiments, it is impossible to know what performance gains can be achieved realistically if design changes are made to the simulated software. For now, we see that there is a performance limit beyond which we cannot go, given the nature of the experiments used in the illustration.

In summary, it was shown that the simulation model could be used to evaluate the baseline configuration proposed. In addition, a series of experiments can be run, each using a slightly altered set of input design parameters.

Finally, from examination of the performance output measures, it is possible to select one or more design options that exhibit desirable performance characteristics.

PART V

Concluding Remarks

In this paper, five out of the six steps outlined in Part II were explained and illustrated. In the interest of brevity, the iterative elements of the procedures and the documentation requirements were not stressed. One illustration does not conclusively demonstrate the usefulness of any procedure nor does it adequately warn potential users of the pitfalls usually encountered during design evaluation activity.

The model developed for the illustration can be extended easily to examine many software design implementations, in addition to the hardware designs shown in this paper. New models appropriate for different application areas also can be easily written using ECSS II. Some examples of software related implementations that might be addressed by an ECSS II model are listed below:

- Preempt-resume CPU dispatching algorithms.
- Priority driven job scheduling.
- Priority driven I/O scheduling.
- Program segmentation and paging.
- Program overlay structures.
- Working set page allocation algorithms.
- Double buffering of I/O.
- Multiprocessor task dispatching.
- Dual channel disk access control algorithms.

Basically, this paper presented two propositions. First, that computer system design evaluation activities should follow the six steps outlined in Part II, and that these activities should be conducted by a design evaluation team made up of users, design specialists, and development specialists. Early use of this procedure introduces discipline to the process that might otherwise be missing. Use of an integrated team of users, designers, and developers, tends to minimize the communication gap problems and probably shortens the overall process.

The second proposition is that computer system simulation is a valuable tool. This tool can be used effectively during the validation phase to articulate designs in the form of readable models, and to gather valuable estimates of performance for each proposed design.

A technique, model, or procedure cannot totally eliminate the risks associated with developing complex weapon systems containing embedded computers. The procedures outlined and illustrated in this paper are proposed because they tend to provide information about the opportunities to evaluate computer system designs in a logical way, and in an environment where hypotheses can be tested. As such, computer system simulation and the six-step procedure in which it is employed can never totally eliminate design risk, but can aid in achieving a significant reduction in design risk. □

NOTE: A paper prepared by Major Feingold during Program Management Course PMC 76-1, Defense Systems Management College, formed the basis for this article. The paper bears AD No. A026387 and is available from the Defense Documentation Center upon request.

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CORRECTIONS Vol. 1, No. 3 – SUMMER, 1977

Page ix.	Line 6,	Reads: "Major John G. Albert, US Air Force, Commandant" **Should read**: Major General John G. Albert, US Air Force, Commandant
Page 1.	Line 1.	Headline reads: "The Process of Standarization" **Should read**: The Process of Standardization
Page 43.	Line 1.	Headline reads: "NATO STANDARIZATION" **Should read**: NATO STANDARDIZATION
Page 65.	Line 12.	Reads: "Ms Avondale L. Stephenson" **Should read**: Ms Avonale L. Stephenson

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